ISSN 1742-1705 Volume 24 Number 1 March 2009

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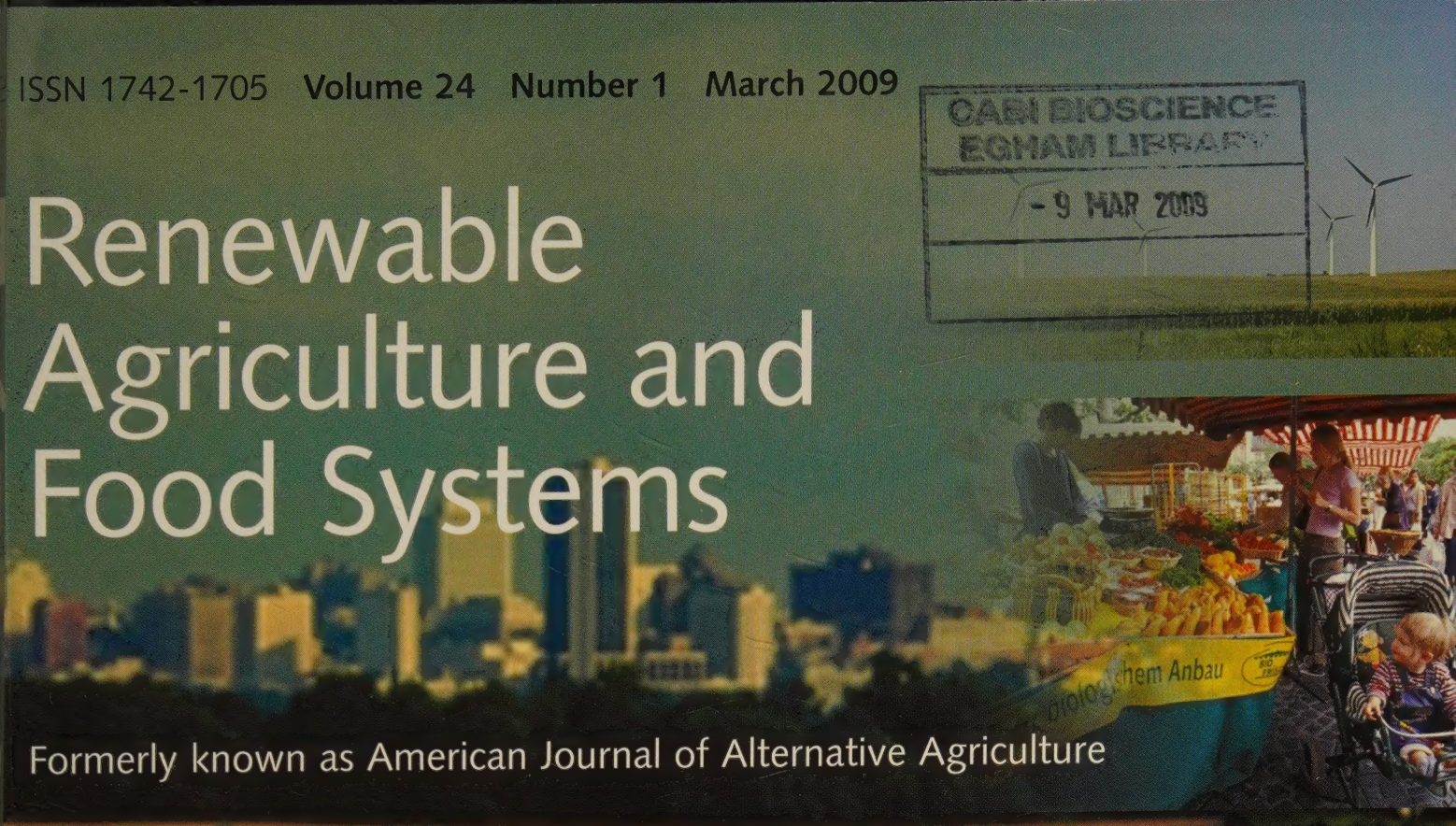
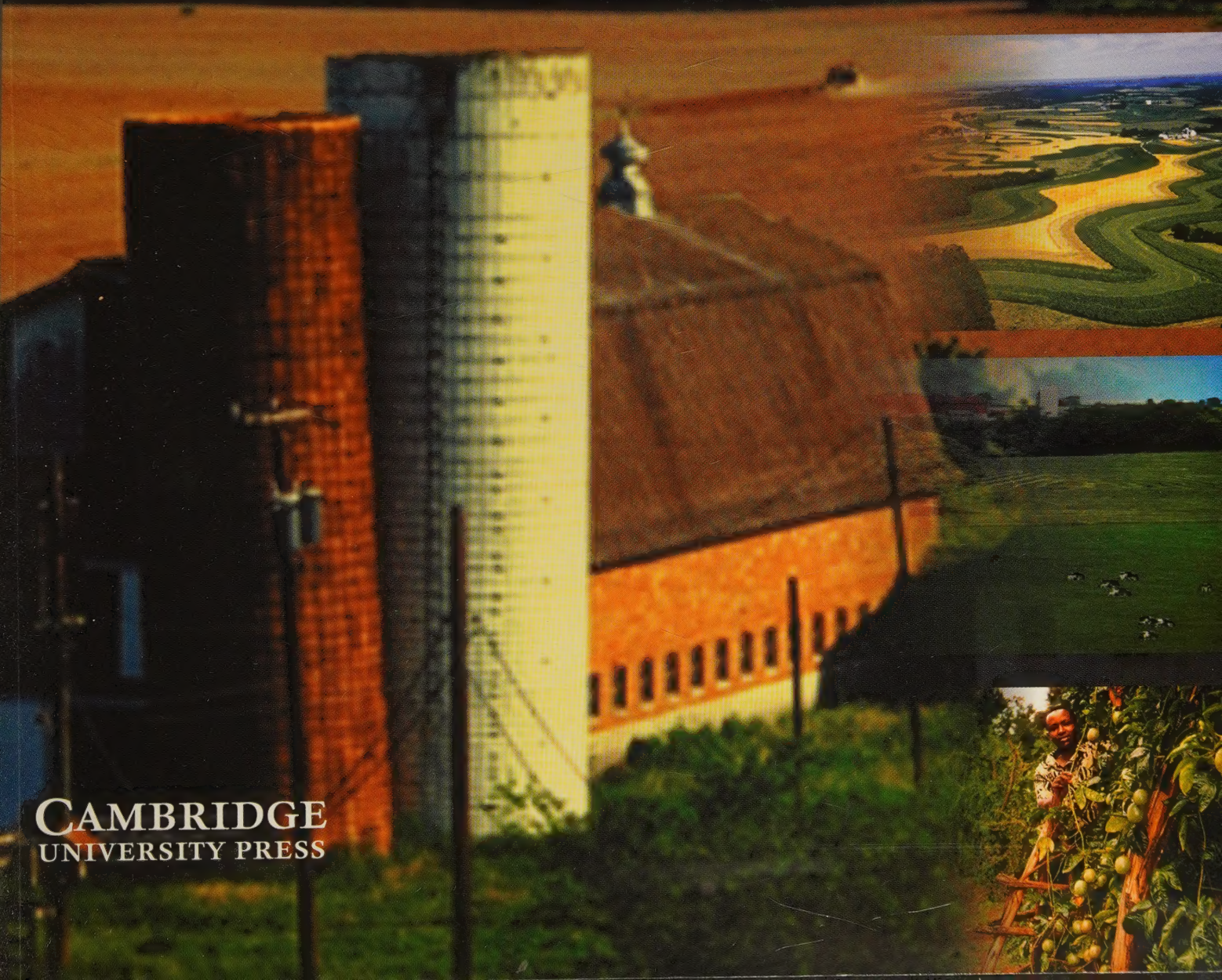
Formerly known as American Journal of Alternative Agriculture





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Renewable Agriculture and Food Systems (ISSN 1742-1705) is published four times a year in March, June, September and December. The subscription price for institutions of Volume 24 (2009) which includes electronic access and delivery by air is £183 (US $360 in the USA, Canada and Mexico); the electronic only price for institutions is £140 (US $270 in the USA, Canada and Mexico). Single parts are £45 (US $86 in the USA, Canada and Mexico), plus postage.

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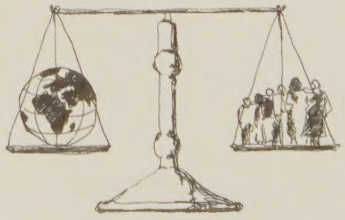

"Sustaining Earth and its People"

Scales image: Design, George Eisele, Lincoln, NE; artwork, Pat Scullion, ASA/CSSA/SSSA, Madison, WI, USA
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Renewable Agriculture and Food Systems: 24(1); 1–7 doi:10.1017/S1742170508002433

Foodshed analysis and its relevance to sustainability

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Accepted 18 September 2008; First published online 8 December 2008 **Commentary**

Abstract

Providing a wholesome and adequate food supply is the most basic tenet of agricultural sustainability. However, sharp increases in global food prices have occurred in the past 2 years, bringing the real price of food to the highest level seen in 30 years (FAO, 2008). This dramatic shift is a fundamental concern. The role of 'local food' in contributing to the solution of underlying problems is currently being debated, and the debate raises a critical question: To what degree can society continue to rely on large-scale, long-distance transportation of food? Growing concerns about climate change, the longevity of fossil fuel supplies and attempts to produce energy from agriculture suggest that energy efficiency will be critical to adapting to resource constraints and mitigating climate impacts. Moreover, these problems are urgent because energy prices, biofuel production and weather-related crop failures are partially responsible for the current world food price situation. Tools are needed to determine how the environmental impact and vulnerability of the food system are related to where food is produced in relation to where it is consumed. To this end, analyses of foodsheds, the geographic areas that feed population centers, can provide useful and unique insights.

Key words: local food, climate change, energy, biofuel, world food situation

Introduction

Agriculture and the food system may be entering a new era. At the end of the 20th century, it was clear that population growth and rising incomes, particularly in developing countries, were increasing global consumption of meat, eggs and other animal products and would have profound impacts on food production and human nutrition in the future[1]. However, just 8 years into the 21st century, climate change, rising energy prices and biofuel production have also entered the world food equation. Each of these forces has been implicated in the recent rise in food prices[2], and they are likely to continue to influence food production over the long term. This adds urgency to the goal of making food systems more ecologically sustainable.

Global concerns about food prices have arisen just as a vigorous discussion has emerged in several modern nations, exemplified by the United States and the United Kingdom, about the merits of organic and local foods. Relative to the larger matter of global food security, debate over the importance of organic and local foods may seem trivial. However, the local foods movement begs a larger question that is quite relevant to both developed and developing nations. Namely, to what degree can long-distance transportation of food continue unabated by concerns about energy and climate change? Indeed, tools are needed to inform policy decisions that, to the extent practicable, simultaneously ensure food security, improve nutrition and reduce greenhouse gas emissions all while adapting to rising energy costs and a changing climate. To this end, analysis of foodsheds, the geographic areas that feed population centers, may provide useful insights. In this paper, we will describe the origin of the foodshed concept and the relationship between local food and sustainability, primarily as they have been addressed in the US. In addition, we will discuss the bearing foodshed analysis might have on global issues such as climate change, energy security and the world food situation.

Concept of a Foodshed and Foodshed Analysis

Analogous to a watershed, the concept of a foodshed has been presented both as a tool for understanding the flow of food in the food system and as a framework for envisioning

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alternative food systems. In what may be the original use of the term, Walter Hedden described a 'foodshed' in 1929 as the 'dikes and dams' guiding the flow of food from producer to consumer[3]. Contemporary authors have used the term to refer to this geographic idea of a foodshed[4,5]. However, the term has also been used to describe the components of an alternative food system that connects local producers and consumers[4,6–8]. Since the term lacks consistent definition, we provide some history of its prior use and clarify its meaning in the context of foodshed analysis.

Hedden's book, *How Great Cities Are Fed*, describes the economic forces that influence where foods are produced and how they are transported to the cities in which they are consumed. His work focused on New York City and was prompted by the threat of a halt in nationwide railroad transportation in October 1921 when 'it immediately became apparent that there was a dire lack of dependable information regarding the city's food needs, the sources from which they were supplied, and the manner in which these supplies were transported and handled'[3]. The fact that 8 million people were fed without anyone understanding the whole system highlights both the power of the marketplace to meet human demands and the peril of taking its function for granted until it is in danger. Hedden does not identify the specific threat, but he likely refers to a scheduled 30 October 1921 strike of the nation's five largest railroad worker unions (railroad conductors, locomotive engineers, switchmen, railway trainmen and locomotive firemen) that would have affected 42 states had it not been called off 3 days before the strike deadline[9,10]. Just as this transportation crisis passed, the term 'foodshed' dropped into obscurity.

Sixty years later, Arthur Getz reintroduced the concept of a foodshed to provide an image that helps people to understand how food systems work and that suggests food comes from a source that must be protected[11]. Getz found this image useful for envisioning how agriculture could thrive in low-density suburban and ex-urban areas by targeting consumers in metropolitan areas. Building on this local theme, Kloppenburg et al. used the term 'foodshed' to represent a more locally reliant, alternative food system that reduces the negative social and environmental impacts of agriculture[4]. Thus, the term often connotes a connection to local food systems even though its original use refers to the food system in general.

Though the literature lacks a precise definition, we adopt the term 'foodshed' here because its parent concept, the watershed, is so widely understood. However, we wish to clarify our use of the term. For the purposes of this paper, a 'foodshed' is the geographic area from which a population derives its food supply. As such, 'foodshed analysis' refers to study of the actual or potential sources of food for a population, particularly those factors influencing the movement of food from its origin as agricultural commodities on a farm to its destination as food wherever it is consumed. Such an analysis would be immediately relevant to the on-going debate about local food but could ultimately be applied to larger questions of food system sustainability.

Local Food and Sustainability

A growing body of literature connects local food to the larger goal of sustainable development. Advocates claim local food systems offer an array of economic, environmental and social benefits, but the evidence underlying these assertions is being challenged. Vigorous debate of these issues has entered the public discourse on food, as evidenced by recent articles in major popular press publications in the US[12] and the UK[13] and the selection of 'locavore' as the Oxford word of the year for 2007[14]. To understand the significance of local food to sustainability, the subject and the surrounding debate must be examined more closely.

The term 'local food' evades easy definition. In part, it is a geographical concept referring to the distance between food producers and consumers. For example, in a recent survey of US consumers, most respondents defined 'local' as produced within 100 miles or within their home state[15]. While several authors claim that no consistent definition of 'local' exists[16,17], terms like 'local food', 'local food system' and '(re)localization' are used almost interchangeably to refer to the concept of increasing reliance on foods produced near their point of consumption relative to the modern food system. In addition to this geographical meaning, 'local food' is also a political concept. This second construction refers to an alternative system of food production that addresses the perceived ills of the modern food system. It has been described as 'a banner under which people attempt to counteract trends of economic concentration, social disempowerment, and environmental degradation in the food and agricultural landscape'[18]. This connection between local and the creation of a more sustainable and just food system has been traced to seminal writings of Wendell Berry, Joan Gussow, Jim Hightower, and Frances Morre Lappé from the 1970s[19].

Given the breadth of the second definition, it is not surprising that a wide range of benefits have been attributed to 'local food'. These purported benefits encompass all three dimensions of sustainability: ecological, economic and social. Some of the advantages of local food arise from the physical proximity of producers and consumers, such as reducing the amount of energy used in the transport of foods[4,7,20,21] and the associated greenhouse gas emissions[22]. Similarly, local foods are purported to be better tasting and perhaps more nutritious than foods bred and picked for their ability to endure long-distance shipping[4,23]. Others benefits are attributed to a combination of shorter supply chains and the relationships forged between producers and consumers, such as improving the economic viability of local farms and their communities[7,21,24], increasing public awareness of issues related to the food system[21], improved environmental stewardship by producers[24] and greater public control over the food system[7,24].

Finally, it has been posited that a more local food system would decrease food safety risks by decentralizing food production[7,21]. Taken together, these claims suggest that 'localization' is a vital component of a transition to a more sustainable and more just food system.

Of course, the validity of these claims has become a matter of debate. Within the scholarly literature, authors caution that there are potential risks (along with benefits) to localizing food systems[16] and that local food systems are not inherently more environmentally sustainable or socially just than the global food system[18,25]. Nonetheless, the weight of the evidence suggests to us that the local food movement is generally viewed in a positive light. Articles in the popular press raise broader issues such as the efficacy of consumer's attempts to promote change through their supermarket purchases[13] and the merits of organic relative to local food[12]. In response to growing public interest, Edwards-Jones et al. examined evidence to see if local food is best, principally in terms of its greenhouse gas emissions[17]. They concluded that because of the dearth of studies which examine greenhouse gas emissions across the entire food system, it is not possible to answer the question conclusively.

Given the contradictory nature of the available evidence, the prevalent claims from local food system proponents should not simply be dismissed. Rather, closer scrutiny is probably in order. More importantly, debate over whether or not 'localization' is desirable or if it is a first principle of sustainability misses a broader point. An interesting question is how might pressing issues of sustainability force the food system to become more local? To this end, several issues stand out because of their urgency and their potential to influence society's continued dependence on long-distance transport of food: namely, the challenges of climate change, petroleum depletion, and bio-energy production beg that this question be answered.

The Climate–energy Puzzle

There is growing consensus within the scientific community that climate change is a threat to sustainability that requires action in the near term. The warming of the planet's climate has been deemed 'unequivocal' by the most recent synthesis report of the Intergovernmental Panel on Climate Change (IPCC), and the available evidence strongly supports the assertion that this change in climate has anthropogenic origins[26]. In addition, while there is no clear agreement on how much warming could be tolerated by the Earth's ecosystems or human society, immediate action seems warranted. The IPCC clearly states that mitigation of emissions can help reduce, delay or avoid many of the negative impacts of climate change and that the risks of severe negative consequences increase the longer society waits to take action[26]. Meanwhile, the Scientific Expert Group on Climate Change and Sustainable Development (SEG) boldly asserts that collective action to address climate change is needed now[27], echoing a sense of urgency which appears to be shared by many scientists[28].

Expert bodies have concluded that since some warming is inevitable, both adaptation to and mitigation of climate change are necessary[27,29]. In addition, since no one sector alone can achieve the level of mitigation required[30], all emissions sectors (agriculture, buildings, energy, forestry and land use change, industry, transport and waste) must contribute to the effort. Since the food system crosses multiple emissions sectors, it is not easy to estimate its total impact. Agricultural production alone contributes 14% of anthropogenic greenhouse gas emissions[26]. However, according to a broader, multi-sector analysis of livestock production, the entire livestock production cycle (from emissions associated with clearing land for crop production or pasture to emissions from processing and transporting livestock products) accounts for 18% of total emissions[31]. Thus, the food system is an important source of emissions, and it is reasonable to evaluate how its impact will be mitigated.

Intimately related to climate change, a second global challenge to sustainability is the depletion of fossil fuel resources amidst rising energy demand. Global hydrocarbon (oil and natural gas) production has been forecast to peak and decline in the 21st century[32,33]. Since oil currently supplies about 35% of the world's energy[34], its depletion poses particular concern. According to a recent report by the US Government Accountability Office, most studies estimate that the peak in petroleum production has already occurred or that it will occur by 2040[35]. This is significant because the peak marks the transition from oil being a plentiful, relatively cheap resource to being an increasingly scarce and expensive resource[36]. Indeed, petroleum production capacity has just been able to keep pace with demand in recent years[35], and rising crude oil prices have surpassed records in both nominal[35] and real (inflation adjusted) terms[37]. Whether or not these price increases indicate that society is near the peak remains to be seen, but they have forced energy back into the public consciousness.

How important is this transition? Several authors believe the consequences are serious enough to warrant close attention, concluding that failure to adequately prepare for the peak will lead to serious economic disruption[33,35,38] or that reductions in population may be necessary to support people at an acceptable standard of living[39]. Others argue that the world can extend the use of petroleum by tapping unconventional sources such as tar sands and oil shale[40,41]. However, such resources are more energy intensive to extract and could significantly increase greenhouse gas emissions[41]. In either case, the energy constraints or potential climate impacts present a clear challenge to sustainability. Moreover, uncertainty about the quantity of reserves remaining and political instability in major oil-producing countries mean production is vulnerable to sudden disruptions[35]. Since the transportation sector is almost completely reliant on oil[35], it is reasonable to

question how movement of foodstuffs will be affected by long-term depletion or sudden disruptions in oil production.

In response to growing concerns about climate change and energy security, biofuels are being sought as a partial solution to both problems. However, while biofuels are a renewable energy source they face several major constraints: the scale of potential production relative to current energy demand, competition with food production and the carbon emissions of land conversion. With regard to scale, it is illustrative to examine the production of ethanol in Brazil and the US, who together produce 70% of the world's ethanol[42]. For example, were the entire US corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) crops used to produce ethanol and biodiesel, just 12% of gasoline demand and 6% of diesel demand could be satisfied[43]. In contrast, the sugar cane (*Saccharum officinarum* L.)-based ethanol industry in Brazil supplied 39% of the country's gasoline demand (based on energy content) with ethanol in 2004[42] even though just 10% of its cropland is devoted to growing sugar cane[44]. However, this comparison is unbalanced because Brazil consumed just 8.4 billion gallons of gasoline in 2004 relative to the 142 billion gallons consumed in the US[42]. Moving beyond these two countries, Giampietro et al. estimated the land needed for 21 countries (including Brazil and the US) to supply both food and energy from agricultural land, assuming that energy needs in temperate regions were supplied from corn and sorghum (*Sorghum bicolor* (L.) Moench) ethanol and in tropical regions were supplied from sugar-cane ethanol[45]. None of the 21 countries included in the analysis had enough arable land to meet both food and energy needs, though Brazil had a more favorable ratio of land needed to land available than the US (3.0 versus 14.6) because of its lower per capita energy consumption and reliance on the more efficient sugar cane-based ethanol system[45]. On balance, 'first generation' biofuels (fuels produced from grains, oilseeds and sugar crops) appear to have limited potential to replace society's current use of fossil fuels.

Even 'second generation' biofuels, which would produce fuel from cellulose, beg the same question about scale. Studies of the potential energy contribution from global biomass production vary widely, but generally suggest that biomass could provide between 100 and 400 exajoules (EJ) of energy by 2050[46]. For comparison, global energy consumption in 2004 was 472 EJ[47]. On the surface, this seems promising. However, the total amount of biomass needed to achieve this level of energy output is comparable with the levels already harvested in the agricultural system[48,49]. Thus, both the ecological and socio-economic consequences of such large-scale production are causes for concern[49].

One such ecological concern is the emission of carbon dioxide from conversion of land to agricultural production. Recent studies have shown that although production of biofuel feedstock removes carbon dioxide from the atmosphere and thus displaces fossil fuel emissions, the net climate impact is greatly influenced by land use change[50,51]. The term 'carbon debt' has been coined to describe the period of time that would be required for a biofuel system to mitigate the emissions caused by converting land to active agricultural use[50]. The size of the carbon debt varies depending on the previous use of the land converted to crop production and the system of biofuel in question. For example, the 'payback' period ranges from 17 years for ethanol derived from sugar cane (*S. officinarum* L.) planted on former savannah to 420 years for biodiesel from oil palm (*Elaeis guineensis* Jacq.) planted on peatland rainforest[50]. Moreover, even if biofuel production itself occurs on active agricultural land, it may push food production onto new land or land that had been abandoned for agricultural use. As a result, even cellulosic ethanol production from perennial crops such as switchgrass (*Panicum virgatum* L.) can indirectly cause land conversion that result in net carbon emissions for decades[51]. Thus, it has been argued that from the standpoint of climate emissions, biofuel production should be derived from waste products[50,51] or from feedstocks produced on abandoned or marginal lands[49,50].

In light of these findings, it seems fair to conclude that society cannot simply 'grow' its way out of the climate change and energy security problems. Nonconventional sources of petroleum can be used as substitutes for conventional oil, but are likely to exacerbate climate emissions. Biofuels are more promising, but face limits in their potential scale and will have to be developed carefully to avoid unintentionally increasing emissions. Thus, more attention must be paid to possibilities for reducing emissions and demand for energy through more efficient transport and different patterns of consumption. To this end, evaluating the potential for strategies, such as increased reliance on local and regional food production, to reduce energy use and emissions is worthwhile.

The World Food Situation

The urgency of these converging problems becomes most apparent when one examines their effect on what has traditionally been the principal goal of agriculture, food production. In the late 1990s, rising incomes and associated dietary shifts were projected to boost consumption of livestock products in the developing world by 2020 and necessitate a significant increase in the intensity of agricultural production[1]. Nonetheless, it was expected that supply would be able to keep pace with demand over this interval[52–54]. While the environmental implications of increased livestock production were a concern, this transformation held promise for improving the incomes of small farmers and adding diversity to the diets of people in the developing world[1].

Recently, assessments of the world food situation have become less sanguine. Global food prices, in real terms, have increased by an average of 15% annually between 2006 and 2008, relative to a modest rate of 1.3% between 2000 and 2005[55]. Poor grain harvests due to droughts,

rising oil prices and increasing demand for biofuels, in addition to the more familiar drivers of rising incomes and population growth, have all been implicated in the rising commodity prices that have caused these increases in world food prices[2,56]. Prior to the recent spike in food prices, food security was already a long-standing concern. Approximately 840 million people suffer from chronic hunger and more than 2 billion suffer from micronutrient deficiencies or 'hidden hunger'[57]. Increases in food prices threaten to reduce the purchasing power of household incomes, pushing more people into deprivation. If this is an indication of how responsive our food system is to climate perturbations and competition between food and energy, then society has cause for alarm.

In this context, a major challenge facing agriculture and the food system in this century will be trying to improve food security and human nutrition while using less fossil energy and reducing its greenhouse gas emissions. Given the tension between agriculture as a source of food and fuel, changing consumption patterns may be essential to achieving these goals. Though lifestyle changes may be difficult to initiate, it is possible to reduce demand for food and feed commodities without sacrificing dietary quality[58]. The most obvious example is reducing excess consumption of calories, which could address both environmental and resource issues as well as health problems associated with obesity. Another example would be substituting plant protein sources for livestock sources, which can reduce the land requirements for growing feed crops while still supplying adequate nutrition. Thus, it is worth investigating how efforts to modify diets might contribute to solving the food–climate–energy puzzle by reducing the demand for the foods that occupy the most extensive areas of land, require the greatest energy inputs or cause the largest emissions of greenhouse gases.

To this end, would shifts to diets based on more local foods reduce energy use or climate forcing emissions? A recent review of the assertion that local food systems emit less greenhouse gas emissions concluded that too few life cycle assessments of food system emissions exist at present to answer the question[17]. Thus, it would appear further analysis is warranted. Moreover, the concept of carbon debt shows that *where* something is grown is as important as *how* it is grown. Thus, facing these problems will require us to reconsider not only *how* food is produced but *where* it is produced.

Foodshed analysis may provide valuable insights into such questions. While attempts have been made to quantify the energy use or greenhouse gas emissions associated with each stage of the food system, the framework of foodshed analysis is unique because it considers geography in two distinct ways. First, a foodshed analysis would entail tracing the flow of food from its origin as an agricultural commodity on a farm to its ultimate point of consumption. Secondly, it would also measure different 'costs' of producing and transporting the products through the system, such as energy consumed, greenhouse gases emitted, or prices paid, not only at each stage in the food system, but for different locations. Such a framework would be valuable for evaluating how the geography of the food system influences its impact on the environment and the vulnerability of populations to disruptions in their food supplies. Moreover, foodshed analysis would help to plan how the geography of food systems should change to enhance sustainability. Many variations on this theme are possible. One example, which is explored in an upcoming paper, is estimating the capacity for population centers to supply more of their food from local sources[59].

Conclusions

Climate change and fossil energy depletion must be addressed in the 21st century. In this process, agriculture will undoubtedly be affected both as a source and sink of climate forcing emissions and a user and producer of energy. Local food systems proponents have long argued that such systems can both reduce greenhouse gas emissions and save energy, but the actual benefits are still a matter of debate. Nonetheless, the urgency of these issues has been highlighted by rising food prices, and analysis is needed to understand how the food system should change to become more sustainable.

To this end, Hedden's impetus for studying foodsheds is illustrative: when the transportation system is threatened, it is imperative to know where food *is* coming from and where it *might* come from. The goals of a foodshed analysis should be to answer either or both of these questions in the context of vulnerability of the food system to perturbations in food production or distribution, but also in the context of assessing the potential for food systems to mitigate greenhouse gas emissions and reduce dependence on fossil energy. Such an analysis should provide valuable insights into the crafting of policy that enhances food security and reduces the food system's ecological impact.

Acknowledgement. This research was supported in part by the National Research Initiative of the USDA Cooperative State Research, Education, and Extension Service, grant number 2005-55618-15640.

References

1 Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., and Courbois, C. 1999. Livestock to 2020: The Next Food Revolution. 2020 Vision for Food, Agriculture, and Environment. Discussion Paper 28. International Food Policy Research Institute, Washington, DC.

2 von Braun, J. 2007. The World Food Situation: New Driving Forces and Required Actions. Food Policy Report No. 18. International Food Policy Research Institute, Washington, DC. Available at Web site http://www.ifpri.org/pubs/fpr/pr18.asp (verified 14 March 2008).

3 Hedden, W.P. 1929. How Great Cities Are Fed. D.C. Heath and Company, New York.

4 Kloppenburg, J. Jr, Hendrickson, J., and Stevenson, G.W. 1996. Coming in to the foodshed. Agriculture and Human Values 13(3):33–42.
5 Stagl, S. 2002. Local organic food markets: potentials and limitations for contributing to sustainable development. Empirica 29:145–162.
6 Pretty, J. 2000. Towards sustainable food and farming systems in industrialized countries. International Journal of Agricultural Resources, Governance and Ecology 1(1):77–94.
7 Halweil, B. 2002. Home Grown: The Case for Local Food in a Global Market. Worldwatch Institute, Washington, DC.
8 Feagan, R. 2007. The place of food: mapping out the 'local' in local food systems. Progress in Human Geography 31(1): 23–42.
9 Anonymous. 1921. Strike to affect forty-two states. The Washington Post, 16 October 1921, 1, 22.
10 Anonymous. 1921. Peace vote unconditional: 'Big Four' unions and the Switchmen act after critical day. New York Times, 28 October 1921, 1.
11 Getz, A. 1991. Urban foodsheds. The Permaculture Activist 24:26–27.
12 Cloud, J. 2007. My search for the perfect apple. Time 169(11):42–50.
13 Anonymous. 2006. Voting with your trolley. The Economist, 9 December 2006, 73–75.
14 Oxford University Press. 2007. Oxford Word of the Year: Locavore. Available at Web site: http://blog.oup.com/2007/11/locavore/ (verified 22 May 2008).
15 Hartman Group. 2008. Consumer Understanding of Buying Local. Available at Web site: http://www.hartman-group.com/hartbeat/2008-02-27 (verified 22 May 2008).
16 Bellows, A.C. and Hamm, M.W. 2001. Local autonomy and sustainable development: testing import substitution in localizing food systems. Agriculture and Human Values 18:271–284.
17 Edwards-Jones, G., Milá i Canals, L., Hounsome, N., Truniger, M., Koerber, G., Hounsome, B., Cross, P., York, E.H., Hospido, A., Plassman, K., Harris, I.M., Edwards, R.T., Day, G.A.S., Tomos, A.D., Cowell, S.J., and Jones, D.L. 2008. Testing the assertion that 'local food' is best: the challenges of an evidence-based approach. Trends in Food Science and Technology 19:265–274.
18 Hinrichs, C.C. 2003. The practice and politics of food system localization. Journal of Rural Studies 19:33–45.
19 Feenstra, G.W. 1997. Local food systems and sustainable communities. American Journal of Alternative Agriculture 12(1):28–36.
20 Gussow, J.D. and Clancy, K.L. 1986. Dietary guidelines for sustainability. Journal of Nutrition Education 18(1):1–5.
21 Gussow, J.D. 1999. Dietary guidelines for sustainability: twelve years later. Journal of Nutrition Education 31(4): 194–200.
22 Pirog, R., Van Pelt, T., Enshayan, K., and Cook, E. 2001. Food, Fuel, and Freeways: An Iowa Perspective on How Far Food Travels, Fuel Usage, and Greenhouse Gas Emissions. The Leopold Center, Iowa State University, Ames, IA.
23 Lapping, M.B. 2004. Toward the recovery of the local in the globalizing food system: the role of alternative agricultural and food models in the US. Ethics, Place, and Environment 7(3):141–150.
24 Lyson, T.A. and Green, J. 1999. The agricultural marketscape: a framework for sustaining agriculture and communities in the Northeast. Journal of Sustainable Agriculture 15(2/3):133–150.
25 Born, B. and Purcell, M. 2006. Avoiding the local trap: scale and food systems in planning research. Journal of Planning Education and Research 26:195–207.
26 IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, R.K. Pachauri and A. Reisinger (eds)). IPCC, Geneva, Switzerland. Available at Web site http://www.ipcc.ch/ipccreports/ar4-syr.htm (verified 29 April 2008).
27 Scientific Expert Group on Climate Change. 2007. Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable. R.M. Bierbaum, J.P. Holdren, M.C. MacCracken, R.H. Moss, and P.H. Raven (eds). Report prepared for the United Nations Commission on Sustainable Development. Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC. Available at Web site http://www.unfoundation.org/files/pdf/2007/SEG_ExecSumm.pdf (verified 18 April 2007).
28 Kerr, R.A. 2007. How urgent is climate change? Science 318:1230–1231.
29 IPCC. 2007. Summary for policymakers. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. p. 7–22. Available at Web site http://www.ipcc.ch/ipccreports/ar4-wg2.htm (verified 29 April 2008).
30 IPCC. 2007. Summary for policymakers. In B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IntergovernmentalPanel on Climate Change. Cambridge University Press, Cambridge, UK and New York. p. 1–23. Available at Web site http://www.ipcc.ch/ipccreports/ar4-wg3.htm (verified 29 April 2008).
31 Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., and de Haan, C. 2006. Livestock's Long Shadow: Environmental Issues and Options. FAO, Rome, Italy. Available at Web site http://www.virtualcentre.org/en/library/key_pub/longshad/a0701e00.htm (verified 29 April 2006).
32 Edwards, J.D. 1997. Crude oil and alternative energy production forecasts for the twenty-first century: the end of the hydrocarbon era. American Association of Petroleum Geologists Bulletin 81(8):1292–1305.
33 Bentley, R.W. 2002. Global oil and gas depletion: an overview. Energy Policy 30:189–205.
34 International Energy Agency. 2007. Key World Energy Statistics. International Energy Agency, Paris, France. Available at Web site http://www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf (verified 22 May 2008).
35 Government Accountability Office. 2007. Crude Oil: Uncertainty About Future Oil Supply Makes it Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production. US Government Printing Office, Washington, DC. Available at Web site: http://www.gao.gov/new.items/d07283.pdf (verified 18 April 2007).

36 Duncan, R.C. and Youngquist, W. 1999. Encircling the peak of world oil production. Natural Resources Research 8(3): 219–232.
37 Mouawad, J. 2008. Oil prices pass record set in '80s, but then recede. New York Times, 3 March 2008. Available at Web site http://www.nytimes.com/2008/03/03/business/worldbusiness/03cnd-oil.html?hp (verified 29 April 2008).
38 Hallock, J.L. Jr, Tharakan, P.J., Hall, C.A.S., Jefferson, M., and Wu, W. 2004. Forecasting the limits to the availability and diversity of global conventional oil supply. Energy 29(11): 1673–1696.
39 Youngquist, W. 1999. The post-petroleum paradigm—and population. Population and Environment 20(4):297–315.
40 Greene, D.L., Hopson, J.L., and Li, J. 2004. Running out of and into oil: analyzing global oil depletion and transition through 2050. Transportation Research Record 1880 : 1–9.
41 Brandt, A.R. and Farrell, A.E. 2007. Scraping the bottom of the barrel: greenhouse gas emission consequences of a transition to low-quality and synthetic petroleum resources. Climatic Change 84:241–263.
42 Seelke, C.L. and Yacobucci, B.D. 2007. Ethanol and Other Biofuels: Potential for U.S.–Brazil Energy Cooperation. Congressional Research Service. Available at Web site http://assets.opencrs.com/rpts/RL34191_20070927.pdf (verified 6 September 2008).
43 Hill, J., Nelson, E., Tilman, D., Polasky, S., and Tiffany, D. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences, USA 103:11206–11210.
44 Goldemberg, J. 2007. Ethanol for a sustainable energy future. Science 315:808–810.
45 Giampietro, M., Ulgiati, S., and Pimentel, D. 1997. Feasibility of large-scale biofuel production: does an enlargement of scale change the picture? BioScience 47(9):587–600.
46 Berndes, G., Hoogwijk, M., and van den Broek, R. 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy 25: 1–28.
47 Energy Information Administration. 2007. International Energy Outlook 2007. Energy Information Administration, Office of Integrated Analysis and Forecasting, US Department of Energy, Washington, DC. Available at Web site http://www.eia.doe.gov/oiaf/ieo/index.html (verified 29 April 2008).
48 Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., and Fischer-Kowalski, M. 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences, USA 104:12942–12947.
49 Field, C.B., Campbell, J.E., and Lobell, D.B. 2007. Biomass energy: the scale of the potential resource. Trends in Ecology and Evolution 23(2):65–72.
50 Fargione, J., Hill, J., Tilman, D., Polasky, S., and Hawthorne, P. 2008. Land clearing and the biofuel carbon debt. Science 319:1235–1237.
51 Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., and Yu, T. 2008. Use of U.S. croplands for biofuels increase greenhouse gases through emissions from land-use change. Science 319:1238–1240.
52 Rosegrant, M.W. and Ringler, C. 1997. World food markets into the 21st century: environmental and resource constraints and policies. The Australian Journal of Agricultural and Resource Economics 41(3):402–428.
53 Alexandratos, N. 1999. World food and agriculture: outlook for the medium and longer term. Proceedings of the National Academy of Sciences, USA 96:5908–5914.
54 Johnson, D.G. 1999. The growth of demand will limit output growth for food over the next quarter century. Proceedings of the National Academy of Sciences, USA 96:5915–5920.
55 Food and Agriculture Organization (FAO). 2008. Soaring Food Prices: Facts, Perspectives, Impacts and Actions Required. High-level Conference on World Food Security: The Challenge of Climate Change and Bioenergy, 3–5 June 2008, Rome, Italy. Available at Web site http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-1-E.pdf (verified 3 September 2008).
56 FAO. 2007. Food Outlook—November 2007. FAO, Rome, Italy. Available at Web site http://www.fao.org/docrep/010/ah876e/ah876e00.HTM (verified 29 April 2008).
57 Kennedy, G., Nantel, G., and Shetty, P. 2003. The scourge of 'hidden hunger': global dimensions of micronutrient deficiencies. Food, Nutrition, and Agriculture 32:8–16.
58 Bender, W.H. 1994. An end use analysis of global food requirements. Food Policy 19(4):381–395.
59 Peters, C.J., Bills, N.L., Lembo, A.J., Wilkins, J.L., and Fick, G.W. In press. Mapping potential Foodsheds in New York State: a spatial model for evaluating the capacity to localize food production. Renewable Agriculture and Food Systems.

Renewable Agriculture and Food Systems: 24(1); 8–18 doi:10.1017/S1742170508002378

A constant goal, changing tactics: The Krusenbaum dairy farm (1996–2005)

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Accepted 1 July 2008; First published online 9 December 2008 **Preliminary Report**

Abstract

This case study documents the trajectory of a successful alternative dairy farm in southeastern Wisconsin. The 1990s were a difficult period for dairying and the Krusenbaum family entered this shifting field in 1990 with a 37-cow Holstein herd in a stanchion barn, 88 tillable hectares and a vision to gradually develop a biodynamic dairy. Low milk prices and the unrelenting workload associated with conventional dairying forced the family to look for alternative strategies. By 1995 they had converted all their land to 47 rotationally grazed paddocks, increased herd size to 70 cows and their annual net farm income had grown to a solid $54,000. The workload remained very heavy, and during the next few years they introduced a swing-16 milking parlor that approximately doubled their milking efficiency and allowed them to again increase herd size, implemented seasonal dairying and constructed an outwintering shed (1997) that greatly facilitated animal management during the winter. By 2002 the farming system had been, by and large, consolidated and by not focusing solely on milk production and crossbreeding with non-Holstein breeds, the herd benefited from improved reproductive vigor. They were then able to synchronize annual calving and the herd's maximum nutritional needs with the spring flush of their pastures, which resulted in lowered purchased feed costs per cow. By this time, annual milk production was fairly constant [around 7400 kg rolling herd average (RHA)], herd health was good and annual net farm income had grown to $75,600. In 2003, the farm became certified organic. With this change the value of the milk increased dramatically from $0.31 liter^{-1} to $0.45 liter^{-1} ($14.27–$20.24 per hundredweight), but feed costs climbed sharply due to the high cost of organic feed, as did labor costs due to the decision to train new farmers in grass-based dairying rather than simply hire employees. Due to very sound farm management, good money management and an entrepreneurial philosophy, this farm, by most performance standards, is now both highly profitable and environmentally sound and the families living on it have a good quality of life.

Key words: management intensive grazing, seasonal dairying, subacute ruminal acidosis (SARA), mastitis, organic dairying, share milking, case study

Introduction

The 1990s were a difficult period for dairying in Wisconsin. The trend of decreasing profit margins that began in the mid-1980s continued as the cost of production increased and real milk prices declined. Net dairy farm numbers continued to decline at the long-term rate of 4–5% per year, from approximately 34,000 at the beginning of the decade to 21,000 in 2000; by 2005 there were only 15,300[1]. The general profile of the remaining dairy farms has also been changing. Whereas between 1985 and 1995, about 90% of the dairies were moderate-sized (30–100 cows), had 70% of the dairy cows and produced about 70% of the milk[2], by 2002, there was a greater concentration of production in large farms. The farms that had more than 200 cows represented only 7% of the dairymen, but they had 31% of the cows and produced 34% of the milk. The under-100-cows group represented only 80% of the dairy farmer population, had 50% of the state dairy herd and produced 46% of the milk[3].

An in-depth analysis of the loss in overall dairy farm numbers in Wisconsin had found that while the exit rate, as a percentage of remaining dairymen, has been fairly constant since the mid-1970s, the entry rate had dropped off significantly in the 1990s[4]. An interesting alternative to the capital-intensive, large-scale confinement operations is the use of the low capital-intensive strategy of management intensive grazing (MIG). It has been estimated that as many

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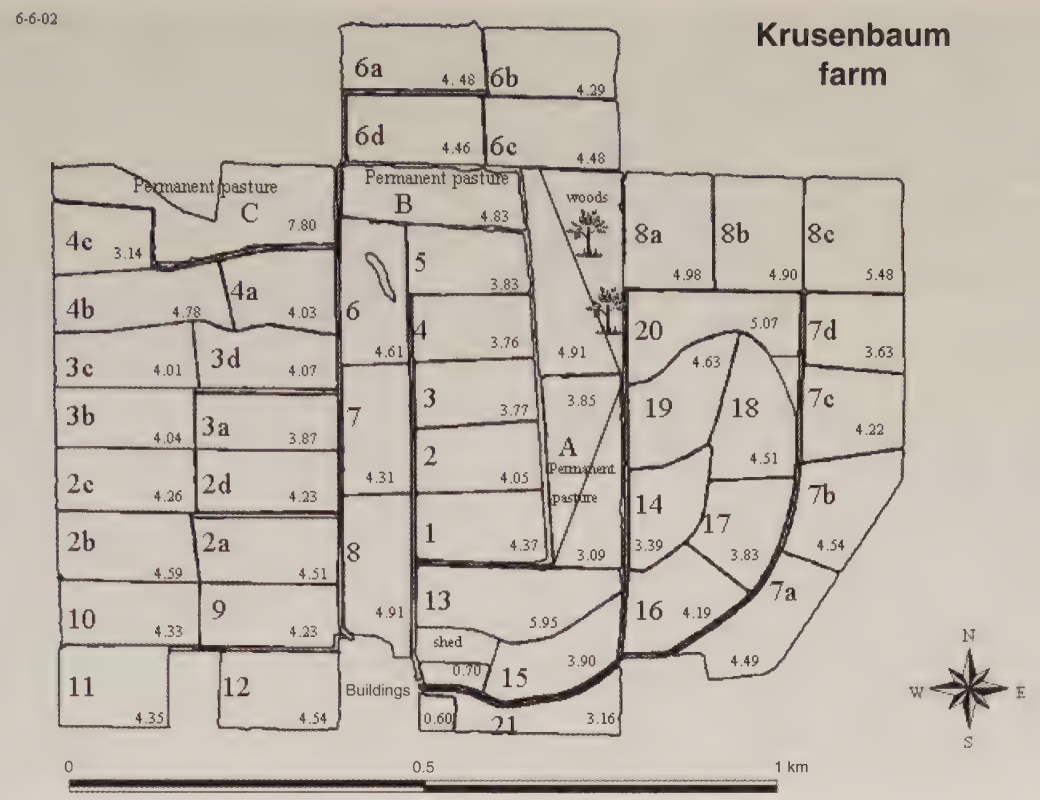

Figure 1. Map of the Krusenbaum field layout.

as 30% of the new entrants into dairying during the late 1990s were primarily using rotational grazing to feed their cows, and a surprising 23% of all dairy farms were using managed grazing (moving the animals at least once a week) in their operation by 2003[5]. The Krusenbaum family entered this shifting field in 1990 and what follows is the sequel (1996–2005) to an earlier paper[6] describing the farm start-up (1990–1995).

A Look Back

In March 1990, the Krusenbaum family leased a dairy farm in southeastern Wisconsin and purchased the existing herd of 37 Holsteins. Their original plan was to establish a mixed farm that included dairying, cash crops, tree crops and vegetables. By the end of 1995, however, the entire farm was seeded down and rotationally grazed (88 ha in 47 paddocks, 4 ha in a woodlot and 4 ha in buildings) (Fig. 1), they were milking 70 cows on a strictly seasonal basis (cows were dried-off in mid-January and began calving in mid-March), and production was at 7700 kg (17,000 pounds) of milk as measured by rolling herd average (RHA). Net farm income (return to the operator and family's unpaid labor and management time) per cow was $790 or $54,000 for the farm[6]. The family was, however, getting ready to install a new 'swing-16' milking parlor (16 milking machines running while on the other side of the pit, 16 more cows are being prepared to be milked) in May 1996. It was estimated that this change would double their milking efficiency (from 40 to 80 cows h^{-1}) and allow them to immediately increase herd size from 70 to 90 cows with the goal of going up to 120. The expectation was that the larger herd size would help the family meet its financial objectives, and the combination of the grazing, the new swing-16 parlor and further improvements in winter management of the livestock (an outwintering shed was constructed in fall 1997) would help the family reach its 'quality of life' objectives. Both members of the couple had experience working on dairy farms prior to starting their own and they knew the work was satisfying but could become both very physically taxing and consume their lives, 7 days a week, leaving little time for family and community. As a result, they continued their focus on the way they would work, but also grew very optimistic about the role that grazing could play in revitalizing the dairy industry and set for themselves, as another 'quality objective', teaching others how to develop MIG dairies.

Methods

We continued to monitor three broad sets of variables: (1) agronomic performance (agricultural production and land stewardship); (2) milk production and herd health; and (3) economic performance. Farm data were collected using a number of different techniques. Soil sampling and on-farm trials were continued, and agronomic and grazing diaries were maintained. Herd production data were monitored by registering with the national Dairy Herd

Figure 2. The interior of the barn constructed in 1997 for the wintering of the cow herd.

Improvement Association (DHIA) program, and economic data were analyzed using the Agricultural Accounting Management Systems (AAMS) software developed by the University of Wisconsin's Center for Dairy Profitability[7].

The monitoring data are presented on three tables following a similar format. The 10 years are divided into three periods: (1) a transition period (1996 and 1997) when the swing parlor and outwintering shed (Fig. 2) were built and herd size grew rapidly; (2) an equilibrium period (1998–2002) when the farm settled into a routine of milking 110–120 cows; and (3) the recent period (2003–2005) when the farm became certified organic.

Where possible, following the data from this organic period is a column representing a 'benchmark' based on a large set of conventional (primarily confinement) dairy farmers. These were developed from either a dairy economic survey (the annual Wisconsin Milk Production Costs Survey–UW Center for Dairy Profitability[8]) or from the annually available DHIA Benchmarks[9].

Agronomic performance

Using the land to feed the herd. The Krusenbaum farm has 88 ha of pasture that include a mixture of bromegrass (*Bromus inermis* L.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), quackgrass (*Elytrigian repens* L.), alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), ladino and white clover (*Trifolium repens* L.). During the grazing season, the milk herd is moved to fresh grass after each milking (2 times per day), and then followed by the heifers. The 1.6 ha (4 acres) paddocks are generally grazed for a day and a half by the milk herd (100 cows, 570 kg each) and then followed over the next day and a half by the heifers (50 heifers, 360 kg each). Regrowth permits cycling through the paddocks five to seven times a season (April 15–November 15). The interval between grazing events starts in the spring at about 14 days and during the heat of the summer may be as long as 45 days. In an average year about 56 ha are hayed in May, and up to 20 ha in June for winter feed. Most of 1000–1200 round bales [270 kg dry matter (DM)] are wrapped put up as high-quality balage. As herd numbers climbed on the farm, an additional 9 ha (1995) and 24 ha (2002) were rented on a long-term basis and custom harvested as haylage.

Repeated sampling during the reporting periods indicated that good-quality forage was available throughout the grazing season [crude protein (CP) = 20–28%; relative feed value (RFV) = 160–180]. However, sward density was lower than desired and trials with potassium fertilization and adding additional manure were undertaken, as well as testing the value of annual frost-seeding of red and ladino clover and ryegrass into the paddocks. Although the increased soil fertility treatments had no impact on paddock productivity, several activities that have been continued maintain, and in some cases increase, sward density. They include: (1) frost-seeding legumes on a rotating pattern into the paddocks in March; (2) clipping the paddocks for weeds and refused forage in June and again in July; as well as (3) extension of the 'rest' periods between grazing

Table 1. Agronomic performance on the Krusenbaum farm.

Agronomic criteria	Krusenbaum farm			Benchmark
	Expansion phase 1996 and 1997	New equilibrium 1998–2002	Organic 2003–2005	Conventional dairy farms 2003–2005[1]
1. Stocking rates (ha per cow)	1.14	1.01	1.12	1.3
2. Purchased feed ($ per cow)	550	294	754	663
3. Machinery costs ($ ha^{-1})	82	131	NA	256[2]
4. Fuel costs ($ per cow)	46	38	72	109
5. Fertilizer and lime ($ ha^{-1})	1	2	8	81
6. Farmgate nutrient budget				
N (kg ha^{-1})	58	67	NA	22[3]
P (kg ha^{-1})	12	10	NA	7[3]
K (kg ha^{-1})	45	67	NA	27[3]

[1] Reference values from the annual Wisconsin Milk Production Costs Survey–UW Center for Dairy Profitability. Mean results from participating dairy farms with 80–120 cows. Sample size from 2003 to 2005 was 145 farms.
[2] Assuming an average equipment complement for a 120 ha dairy farm with 40% of the area in hay and 60% in new seedings and corn (University of Wisconsin-Extension, 2001).
[3] Farmgate budget from a survey of 19 dairy farms in southern Wisconsin[10].

beginning in June from 15 to 30 days. This latter approach has been the most effective. Nevertheless, summer rainfall remains the largest determinant of forage production. Poor pasture and forage production were recorded in 1995, 1997, 2002 and 2005. Moisture deficits were the common factor in these years: June 1995 rainfall was only 25% and July 2002 was only 15% of the 30-year norm; while the dry spring of 1997 (50% of long-term average for April/May) was exacerbated by the previous year's late summer (August/September) rainfall of only 4.3 cm (20 cm norm), resulting in depleted subsurface moisture. Forage production was the lowest in 2005 due to the combined problems of moderate to severe winterkill on the pastures and hay ground during the open, icy month of January, and grazing season rainfall (April–October) that was the lowest it had been since they moved on to the farm. Winter feed storage dropped to a low of 200 tons (DM), whereas in normal years it is closer to 650 tons (DM).

The stocking rate on the farm when the rented area is included is similar to the benchmark operations (Table 1, line 1) and well above the recommended limit of at least 0.72 ha per cow[11]. During the expansion stage (1996 and 1997), purchased feed costs per cow were high (Table 1, line 2). This was due to the back-to-back seasons of low winter moisture reserve and low grazing season rainfall, resulting in poor paddock production. During the equilibrium stage (1998–2002), with more normal rainfall, paddock production increased and feed purchases per cow returned to $294 or only 50% of that of the conventional benchmark herds. Once the farm became certified and organic corn and alfalfa were required, feed purchases per cow increased, especially during the dry year of 2005 ($950 per cow). As a result, average feed purchases are now slightly higher than that of conventional dairies of approximately the same size.

Evolving machinery park on the farm. Initially the farm was set up with a typical complement of equipment for a small conventional dairy farm. During the first 6 years (1990–1995), machinery costs per hectare were fairly constant ($62 ha^{-1})[6] due to the costs incurred as their row crop equipment became unnecessary and was sold (at a loss), and to their decision to buy equipment allowing them to wrap round bales and make round bale silage. The more recent data (Table 1, line 3) show that machinery costs on the farm have climbed somewhat as herd size increased, resulting from their decision to buy newer equipment to meet the increased need to put up winter feed. However, machinery costs still represent only about 50% of the university's estimates for a conventional dairy farm[12]. The explanation for the difference is that less machinery is needed on a rotational grazing operation and it is used on relatively few acres. For example, on a conventional dairy all the fields are crossed with machines several times a year in a typical corn and alfalfa rotation. Fuel use per cow (Table 1, line 4) also remains low and well below that of the conventional benchmark farms.

Manure management, farm gate budgets and soil test values. Manure spreading on the farm is based on regular soil testing every 3 years (one composite sample every 3 ha). Generally there is enough manure in the outwintering barn to manure 16 ha (25 tons ha^{-1}) in the spring

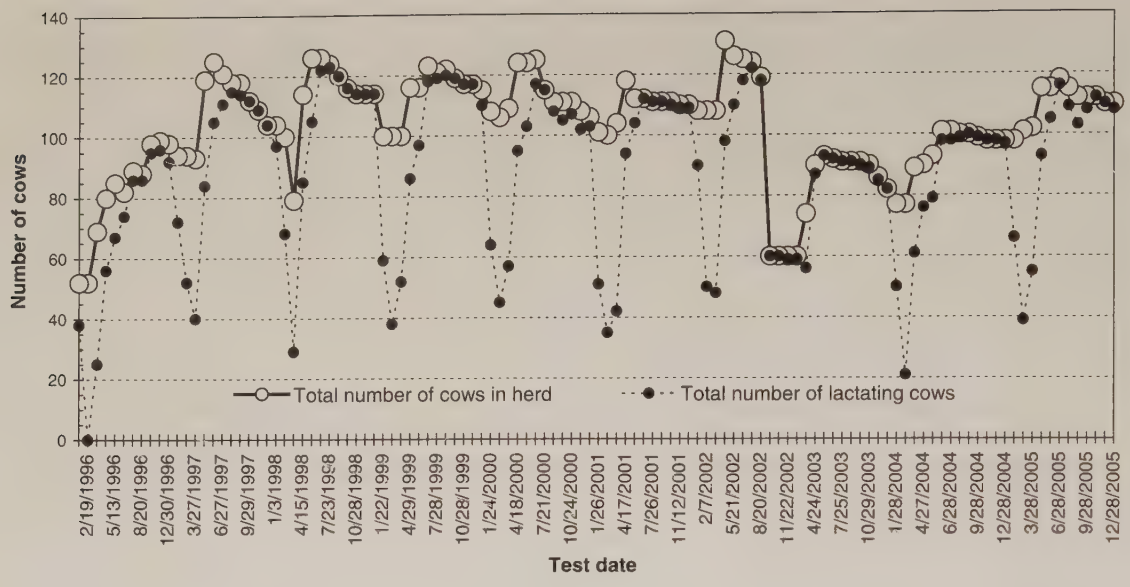

Figure 3. Evolution of adult cow numbers on the Krusenbaum farm.

and the yard scrapings in the winter are equivalent to approximately 30 tons week^{-1}. Generally manuring rotates around the farm over a 6- or 7-year cycle with greater emphasis on manuring the low soil test rented fields and less emphasis on the fields near the tree lines where manure accumulates during winter feeding from the round bales.

The increase in herd size from 70 (1995) to 120 animals (1998) was accompanied by only a modest change in estimated nutrient accumulation on the farm (Table 1, line 6). This was due to the fact that more land was rented for making hay, keeping purchased feed to a minimum as well as giving them a larger base for spreading manure. Due to modest phosphorus and protein feed purchases the P-budget is generally in balance and this is reflected by soil test values (0–15 cm) taken in 2007. Although the farm mean of 112 ppm is high (31 sampling stations), it has been constant, in spite of the increased number of animals. Potassium accumulation, however, has been taking place, but this is a good thing as soil test levels have been low on the farm (1990 = 81 ppm and 2007 = 114 ppm) and an increase in soil organic matter levels (1990 = 2.7% and 2007 = 3.3%) due to the perennial sod has also been noted.

Land stewardship. The entire farm has been in grass since 1995, and beginning in 1997, increased attention has been paid to 'traffic problems' caused by wet winters and rotational grazing. With the construction of the outwintering shed, they have had the option to keep the animals off the paddocks during the muddy season (March/April) and to feed them near the shed. This has prevented a lot of pugging in the paddocks and damage to the sward. The second investment was to put in new 5–7 m wide lanes with the help of a Natural Resources Conservation Service (NRCS) EQIP cost-sharing program ($18,000, farm; $50,000, Federal Government). The improved lanes and well-designed culverts greatly facilitate animal and machinery movement and ultimately animal health.

Milk production and herd health

Throughout most of the dairy industry, the primary emphasis of herd performance is maximized milk production per cow per day. While milk production is always important, in grazing dairies it becomes less important than synchronizing the time of maximal nutrient needs of the herd with the season of maximal pasture growth. This concept underlies many of the herd management strategies employed by the Krusenbaum dairy in its evolution to a grazing dairy operation.

Herd size. Between 1996 and 1997, the herd increased in size from approximately 70 to 120 cows, as shown in Figure 3. Once achieving a herd size of approximately 120 cows, herd size remained relatively stable until late in 2002. A drought in the spring and summer of 2002 created a severe shortage of stored forage heading into the winter and a decision was made to reduce herd size temporarily to 60 cows rather than purchase feed for the winter. Because relatively few cows are culled from the dairy, herd size rebounded to a total of 95 in 2003, 100 in 2004 and approximately 115 by the grazing season of 2005.

Milk production. The most common index of herd milk production in the US dairy industry is RHA milk (Table 2, line 1). RHA is an estimate of the average total weight of milk produced per cow in the herd over the previous 365 days. While RHA is obviously primarily a reflection of level of milk production of the cows, it is influenced greatly by length of dry periods, calving intervals and other herd management factors. For example, increasing the length of the dry period of a cow does not change the number of cow-days in the herd, but would reduce the number of days when milk is being produced.

In addition to increasing herd size for the 1997 grazing season, the practice of shutting down milking operations early in the year was modified, as shown in Figure 3. In

Table 2. Herd performance on the Krusenbaum farm.

Herd performance criteria	Krusenbaum farm: Expansion phase 1996 and 1997	Krusenbaum farm: New equilibrium 1998–2002	Krusenbaum farm: Organic 2003–2005	Benchmark: Conventional dairy farms 2003–2005[1]
1. RHA (kg per cow)	6850	7355	7432	9477
2. Days dry per year	77	60	57	63
3. Calving interval (months)	12.8	12.1	12.1	14.1
4. First lactation cows, average age at calving (months)	24	23	24	27
5. Culling rate (% of herd)	37	29[3]	24	37
6. Holstein cows (% of herd)	100	70	55	95
7. Somatic cell count ($\times 1000\,ml^{-1}$)	384	241	293	326
8. Milk fat (%)	3.18	3.49	4.02	3.82
9. Veterinary costs ($ per cow per year)	74	69	84	106[2]

[1] Reference values, AgSource, Wisconsin DHIA, All Holstein Herds, December 2003–2005.
[2] Reference values from the annual Wisconsin Milk Production Costs Survey–UW Center for Dairy Profitability. Mean results from participating dairy farms with 80–120 cows. Sample size from 2003 to 2005 was 145 farms.
[3] Excludes 2002 when 50% of the herd was sold following a drought and a shortage of forage to winter the herd.

order to take a break from milking in winter, they had to stop milking a number of good producing cows relatively early in their lactation, which became viewed as a very costly practice every year. From 1997 onwards, the number of cows being milked through the winter usually stabilized at approximately 40%. There were cases, however, where winter labor was short and they did close down milking altogether. Nevertheless, in the summer months, it was typical for 100% of the cows to be producing milk. This change in winter milking policy resulted in reductions in the average length of dry periods from 83 days in 1994 and 1995[6], to close to the industry standard of 62 days by 2002 (Table 2, line 2). Milk production per cow climbed slightly following the transition period and, by 2002, RHA milk at 7355 kg per cow per year was about 80% of the average DHIA Holstein herd production. Milk production per cow climbed again slightly during the organic phase but now represents only 78% of the average DHIA Holstein herd production (2003–2005) (Table 2, line 1). While below average milk production per cow may appear to be undesirable, it may be consistent with achieving the larger goal of maximizing pasture use efficiency.

Herd reproduction. In the MIG system, unlike a system that depends on stored feed, it is crucial that the majority of the herd calves just prior to the onset of the spring flush in the pastures when the feed is most abundant and of highest quality. Approximately 60 days after the birth of the calf, a cow reaches her peak milk yield, which coincides with her peak nutrient needs and her maximal intake of feed. Following peak, milk production declines gradually over the subsequent months until the cow is 'dried off' or milking ceases. As a dry cow, she will consume less than half the amount of feed per day as when she was at peak milk production. To maintain this rhythm of the majority of the herd calving in March and April, the rate of successful identification of 'heat' (estrus) and insemination every 12 months must be very high. If, for example, the herd calving interval were to spread to 13 months for 6 years, cows would calve in the autumn and would require stored feed for most of their peak production period. Thus, in a seasonal grazing dairy, reproductive management to achieving a 12-month calving interval becomes actually more important than increasing milk production per cow (Table 2, line 3).

Maintaining an annual calving cycle in dairy cows has become a very difficult process that is rarely achieved in the industry today. In a review of reproductive trends in the US dairy industry, Lucy[13] reported that average calving intervals of 13.3 months in 1970 had stretched to 14.7 months by 2000. The longer calving intervals were mirrored by reduced fertility, measured as services per conception, which increased from 1.8 in 1970 to 3.0 in 2000. During this same 30-year period of time, production increased from 6400 to approximately 9000 kg of milk per cow per year. Simply stated, reproduction and milk production appear to be antagonistic.

In the case of a grazing dairy where there is a seasonality of forage availability, it appears that if lower production is

the price that must be paid to maintain an annual calving rate, farm profitability may not be adversely affected, as it would in a dairy based on stored feeds. While this dairy is below average in terms of milk production, it has achieved the unusual accomplishment of a 12.1 month calving interval over the past several years—a full 2 months sooner than in the conventional herds in Wisconsin (Table 2, line 3). The seasonal imperative for spring calving also means that replacement heifers must be managed so that they calve at 23–24 months of age, not at 27 months as is the average in the conventional herds (Table 2, line 4).

In 1994–1995, 56% of the herd was culled[6]. Many of these cows were sold because their calving intervals had stretched to where they would not calve back in the desired early spring 'calving window'. By moving to a more flexible seasonal milking program and having animals in excellent reproductive health, the farm was able to reduce its culling rate to 24% in recent years, dramatically less than the 38% culling rate common in the industry (Table 2, line 5). This number is even more remarkable considering that only half of these animals were involuntary culls (disease, don't get pregnant), while the remainder were sold to other dairies (pregnant but going to calve outside the 'calving window'). In conventional dairies, nearly 100% of the cull animals are involuntary and sent directly to the slaughterhouse.

Herd genetics. One of the reasons for the lower milk production per cow on this farm is due to genetic selection for traits other than milk production. In 1995, the adult cowherd was 100% Holstein with most cows fathered by high-production bulls using artificial insemination[6]. During the transition period however, much of the service sires or semen being used in the active breeding program was purchased from New Zealand Friesian bulls and a number of cows were being bred to non-Holstein bulls. The primary cross has been between Holstein and Jersey, but semen from Normande, Dutch Belted and Scandinavian Red bulls has been used to breed some Holstein cows. Because the semen of several breeds was purchased from several countries, comparable genetic index values cannot be provided in this discussion. This policy continued during the new equilibrium phase and, by 2002, 30% of the cows in the herd were crossbreds and by the end of 2005, 45% of the cows were crossbreds (Table 2, line 6). In comparison with the overall industry, approximately 95% of the dairy cows in the AgSource data set maintained by Wisconsin's DHIA testing service were purebred Holsteins in 2005.

Milk volume from the crossbreds is expected to be less than that of purebred Holsteins because the starting point of the other breeds is so much less[14]. However, the crossbred cows are expected to show hybrid vigor resulting in increased fertility, longevity and calf viability[15]. The current excellent reproductive performance of the herd may be partly due to absolute reduction in milk yield of the herd as sire selection has not emphasized milk volume, partly due to improved fertility related to hybrid vigor of the crossbred cows and, of course, excellent management. Again, both factors of reduced yield and hybrid vigor would favor reproductive health so that calving can coincide with the spring flush of pasture growth.

Herd health.

Mastitis. While pastures present very clean conditions for the cows and are associated with excellent mastitis control, outwintering the cows on pastures presents risks for cows in the late winter and early spring. When the stanchion barn was converted into a milking parlor in 1996, the cows no longer had a barn for housing. And as the frost leaves the soil in March and April, the feeding areas in fields can become muddy and soiled and the teats become contaminated, a risk factor for mastitis infections.

The standard monitor of mastitis is the herd average somatic cell count (SCC). Herd average SCC of 150,000 per milliliter of milk or lower is considered excellent, whereas herd average SCC greater than 500,000 is considered to represent herds where a large proportion of the cows have infections of their mammary glands. As shown in Figure 4, and Table 2, line 7), the herd SCC exceeded 500,000 in the early months of both 1996 and 1997, a problem attributed to the outside conditions. Although the herd SCC improved when the grazing season began, mastitis problems in the first weeks after calving are a serious health and production risk to the cow.

Because of these mastitis problems with the fresh cows, and for cow comfort, a barn with a straw bedded pack and cement floor outside the feeding area was constructed and used first during the winter of 1997–98 (Fig. 2). The new barn improved the hygiene of the cows through the late winter and early spring and was associated with excellent mastitis control from the summer of 1997 to 2000. An increase in herd SCC in the winter of 2001 was not diagnosed as to cause.

Since the herd achieved organic status, the use of antibiotics on the mammary glands, called 'dry cow treatment', has been discontinued. Dry cow treatments are a standard practice in the US dairy industry, as they have been shown to eliminate some of the existing subclinical infections and have been effective in reducing the number of new cases. The herd average SCC during the first 3 years of the organic phase has averaged 293,000, a modest increase over previous years (Table 2, line 7). While managing the herd on pasture resulted in excellent udder cleanliness and reduced risk of mastitis infections, the inability to use antibiotics in an organic dairy reduces the ability to manage mastitis infections and has resulted in an increased SCC for the herd.

Subacute ruminal acidosis (SARA). Milk production declined by 13% in 1996 and 1997 from prior levels. For example, in June of 1995, the herd had averaged 80 lbs of milk per cow per day, but produced 66 and 67 lbs per cow per day in each of the subsequent June test dates, respectively. Herd average milk fat percentage reached

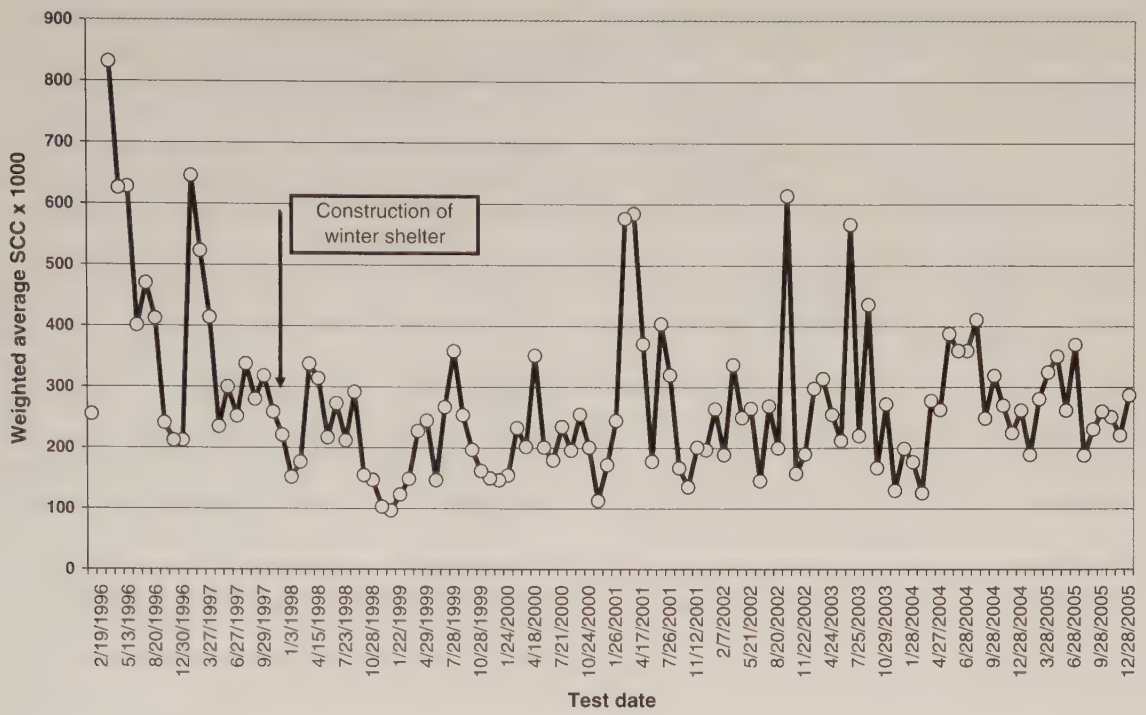

Figure 4. Herd average SCC.

very low levels of 2.7% in the grazing season of 1997. Because low production and low milk fat percentage are commonly found in herds experiencing SARA, an investigation was conducted. Using the rumenocentesis test[16], a positive diagnosis of SARA was made. SARA usually occurs in cattle being fed diets with an excess of starch, resulting in excessive production of volatile fatty acids and lower ruminal fluid pH below 5.5[17]. In grazing cattle, highest milk yields are associated with ruminal pH between 5.8 and 6.2[18].

Following the diagnosis, various modifications were made to the feeding program to reduce the ruminal acidosis problem. The daily feeding of corn grain (7 kg day^{-1}) was reduced and, by 2001, was approximately 3.5 kg per cow per day. The reduction in corn grain was replaced by increased consumption of purchased alfalfa silage and, by 2001, ruminal pH values returned to the normal range. This modified feeding program replacing grain with forage may partly explain, along with genetics, why the RHA milk production is below that of comparable conventional dairies. Similarly, the improved control of ruminal acidosis would have contributed, along with crossbreeding with breeds that produce higher fat content milk, to the increased milk fat percentage in the past few years (Table 2, line 8). As with many grazing-based farms, the overall health of the herd has been good and veterinary expenses ($84 per cow per year) now represent about 80% of the costs incurred by conventional dairies (Table 2, line 9). Even these numbers are a bit high and this is largely due to a commitment to animal welfare and high-quality health care. They do not spare expense on animal health. A result of this philosophy is that these dairy cows remain in the production herd for an average of 4.2 lactations, whereas the industry average is 2.7.

Economic performance

As with any business, success must also be measured in economic terms. Table 3 summarizes several whole-farm economic indicators and provides industry benchmark comparisons from similarly sized farms (80–120 cows) from the AgFA survey results[8]. Total farm income per cow was fairly constant from 1996 to 2002, while actual herd numbers markedly increased from 69 in the fall of 1995 to 115 in the fall of 2001. And then total farm income per cow increased dramatically once the farm became certified organic and was nearly equivalent (94%) to the conventional dairy benchmark (Table 3, row 2). Most of this income was from the sale of milk and it appears that, although production levels were lower on the Krusenbaum farm (by 2000 kg per cow from Table 2, line 1), high organic milk prices ($0.45 liter^{-1} versus $0.31 liter^{-1}) mostly offset this effect.

A historical strength in the Krusenbaum system has been their low cost structure (inputs, labor and interest payments). Basic cost per hundredweight equivalent (CWT EQ) is a measure of the input costs that farmers incur in generating total farm income, by converting all their income streams (milk, cull animals, custom work, and crop sales) to milk equivalents (Table 3, row 3). During the equilibrium phase, these input costs were 85% of that of conventional dairymen. Since becoming certified organic, however, basic costs have gone up and now are equivalent to the baseline sample, in large part due to the increased

Table 3. Economic performance on the Krusenbaum farm.

Economic criteria	Krusenbaum farm			Benchmark
	Expansion phase 1996 and 1997	New equilibrium 1998–2002	Organic 2003–2005	Conventional dairy farms 2003–2005[1]
1. Average number of cows	85	111	96	96
2. Total farm income ($ per cow)	2520	2779	3709	3946
3. Basic cost ($CWT EQ^{-1})[2]	8.56	7.55	8.75	8.68
4. Labor costs ($ per cow)[3]	252	128	272	362
5. Interest payment ($ per cow)	160	114	62	159
6. NFIFO ($ per cow)[4]	242	670	775	752
7. Net farm income ($ per year)	23,240	75,600	73,595	74,088

[1] Reference values from the annual Wisconsin Milk Production Costs Survey–UW Center for Dairy Profitability. Mean results from participating dairy farms with 80–120 cows. Sample size from 2003 to 2005 was 145 farms.
[2] Basic cost per CWT EQ measures the input costs that farmers incur in generating total farm income, by converting all their income streams (milk, cull animals, custom work and crop sales) to milk equivalents.
[3] Direct labor costs for non-family members minus benefits.
[4] Net farm income from operations (NFIFO) is the return to the operator family's unpaid labor and management plus the return to their equity capital.

cost of buying certified organic feed. This measure does not include the effects on cash expenses associated with paid labor or debt servicing. In fact, on many farms labor and interest payments add greatly to the actual costs of production. On the Krusenbaum farm, cash labor expenses per cow to non-family members were lowest during the equilibrium stage (1998–2002). Although labor costs for the recent period are still only 75% of those on conventional farms, they have more than doubled from that lowest point, primarily due to the presence of a pair of interns (married couple) and part-time employment of a neighbor (Table 3, row 4). The third component of the cost structure for producing milk is debt servicing. It is especially noteworthy that although the Krusenbaum farm has a modern milk parlor, an outwintering shed and a good line of farm equipment, it is carrying only 40% as much debt per cow as the benchmark farmers (Table 3, row 5).

The third group of economic variables reflects the actual income available to the farm family. Net farm income from operations (NFIFO) per cow (Table 3, row 6) is strictly the return to family labor, management and equity capital. Due to the construction of the swing parlor and outwintering shed plus the adoption of seasonal dairying during the transition period, the farm experienced a low NFIFO per cow during those two years. However, during the equilibrium phase, when the construction was paid for and milk production was up, NFIFO per cow improved markedly. This number is also enhanced by a number of additional enterprises on the farm. They raise about 25 steers; have range-grown broilers and eggs; and grow a few pigs every year that they market (gross sales $40,000). During the organic period, although production costs had risen (inputs and labor), the high price of organic milk ($0.45 litre^{-1}) resulted in still higher returns per cow, equal to that of the conventional benchmark herds. And this was accomplished at only 80% milk production levels. Net farm income on the Krusenbaum farm (Table 3, row 7) both during the new equilibrium period and organic period has been nearly equivalent (102 and 99%, respectively) to conventional benchmark farms. The NFIFO per cow and net farm income both clearly indicate that this farm is a financial success.

Conclusions

The Krusenbaum farm, from all the indicators, is a success. The home farm plus rented land is supplying most of the dairy feed, the presence of well-managed pasture and improved lanes have resulted in almost no soil erosion on the farm, and soil test phosphorus levels are remaining constant, while needed levels of potassium and organic matter are increasing. Milk production is modest but steady and the problem of subacute ruminal acidosis has been solved. Most striking is the reproductive health of the herd, which allows for an excellent synchronization of herd feed needs with the spring flush of forage. Net farm income on the farm is equivalent to that of the benchmark sample, adequate labor has markedly reduced the stress of farming and the low level of annual interest payments all bode well for the future.

This farm has been a success, we hypothesize, for the following three reasons:

(i) ***The production strategy underpinning the farm operations is valid.*** Almost all of the herd management decisions have been focused on synchronizing calving with the spring flush of pasture, assuring that when the herd's nutritional needs are the highest, high-quality, cheap forage is plentiful.

(ii) ***Management has been creative and flexible.***

Farm management. The Krusenbaums have continually tried to improve their system through the building of an outwintering shed, a new parlor, expanding the cow lanes and shifting to strictly seasonal and then backing off to partially seasonal dairying. Although it took nearly 2 years to develop a diet that reduced rumen acidosis, by working closely with nutritionists they were able to solve the problem.

Investment decisions. The family was not afraid of investing money to improve their operation. Although an indirect measure of their willingness to invest, depreciation per cow over the past 10 years has been $420 or $61 per cow higher than the confinement dairy benchmark sample. They have a modern milking parlor, outwintering building and a first rate line of equipment for putting up forage as balage for winter feeding. By attention to detail, they have made each of these investments generate additional income due to the resulting labor savings or quality of the feed they harvested.

Money management. They have kept their debt-to-asset ratio low by shopping around for money when they needed it. Although they now have one of the largest dairy grazing operations in the state, they are carrying relatively little debt.

Entrepreneurial spirit. The Krusenbaums have continually looked for ways to develop value-added products and synergies on their farm, allowing them to increase farm income. They raise about 25 steers each year, which they market. They introduced a small poultry and egg operation that follows the rotating herd in the paddocks and helps break up the manure pies, and they have had several pigs per year that rut in their outwintering shed, helping to mix the hay and manure pack into compost. They also collaborated in an unsuccessful effort to market part of their milk as a grass-fed, locally produced cheddar cheese, but discontinued their participation when it proved uneconomical. The successful initiatives play a small but important role in the profitability of this operation.

(iii) ***The family has always prioritized quality of life issues.*** Dairying can result in a crushing lifestyle. Since the Krusenbaums started in 1990, the issue of quality of life has driven most of their major decisions. Starting with the shift from conventional to rotational grazing (1993 and 1994), the purchase of modern baling and wrapping field equipment (1995 and 1996), the shift to partial seasonal dairying and herd expansion and the construction of the dairy parlor (1996 and 1997), and the building of the outwintering shed (1997) have helped them meet their goal of making dairying a good family enterprise. And most recently, they have been dedicating more time and resources to training a new generation of dairymen using MIG techniques. In addition to participating in the university's School for Beginning Dairy Farmers and a local grazing network, they have developed a share milking agreement (2006). (Under this contract the young couple who were interns, and want ultimately to own their own dairy, manage the farm, and pay 16% of the variable costs. In return, they keep 16% of the monthly milk check, get free housing, and are building equity by keeping every fifth heifer calf.) The Krusenbaums' focus on quality of life issues was one of their most important decisions and they are today as enthusiastic about dairying as when they started in 1990.

Acknowledgements. The Krusenbaums have been unstinting in their honesty and graciousness in sharing information with the project team over the past 18 years. This would not have been possible without the close collaboration of the Michael Fields Agricultural Institute of East Troy, Wisconsin.

References

1 Wisconsin Agricultural Statistics Service. 2006. Wisconsin Agricultural Statistics-2005. USDA National Agricultural Statistics Service, Madison, WI.

2 Barham, B. 1998. What is the future of Wisconsin's moderate-scale dairy farm? Program on Agricultural Technology Studies. Staff Paper No. 1. University of Wisconsin, Madison, WI. Available at Website http://www.pats.wisc.edu

3 Barham, B., Foltz, J., and Aldana, U. 2005. Expansion, modernization and specialization in the Wisconsin dairy industry. Program on Agricultural Technology Studies (PATS). Research Summary No. 7. University of Wisconsin, Madison, WI. Available at Website http://www.pats.wisc.edu

4 Program on Agricultural Technology Studies. 2001. Dynamics of entry and exit on Wisconsin dairy farms in the 1990's. Wisconsin Family Farm Facts No. 14. University of Wisconsin, Madison, WI. Available at Website http://www.pats.wisc.edu

5 Taylor, J. and Foltz, J. 2006. Grazing in the dairy state: pasture use in the Wisconsin dairy industry, 1993–2003. Center for Integrated Agricultural Systems (CIAS) and the Program on Agricultural Technology Studies (PATS), University of Wisconsin, Madison, WI.

6 Posner, J., Frank, G., Nordlund, K., and Schuler, R. 1998. Constant goal, changing tactics: a Wisconsin dairy farm start-up. American Journal of Alternative Agriculture 13:50–60.

7 Agricultural Accounting Management System (AAMS) software. Available from the UW Center for Dairy Profitability. http://cdp.wisc.edu/Software.htm (accessed 30 July 2008).

8 Agricultural Financial Advisor (AgFA) Interactive Data Set from the UW Center for Dairy Profitability. Available at Website http://cdp.wisc.edu/AgFA.htm (accessed 30 July 2008).

9 Dairy Herd Improvement Association. Annual Benchmarks Website. http://agsource.crinet.com/page849 (accessed 30 July 2008).
10 Fisher, D.K., Posner, J.L., and Baldock, J.O. 1996. Whole-farm nutrient budgeting on 30 crop/livestock operations in the Upper Midwest. Agronomy Abstracts. American Society of Agronomy. 1996 Annual Meetings, Indianapolis, IN, 3–8, November 1996. p. 59.
11 Program on Agricultural Technology Studies. 2005. Manure Management on Wisconsin Dairy Farms. Fact Sheet 23. University of Wisconsin, Madison, WI. Available at Website http://www.pats.wisc.edu
12 University of Wisconsin-Extension. 2002. Wisconsin Custom Rate Guide-2001. Extension Fact Sheet A3656. University of Wisconsin-Extension, Madison, WI.
13 Lucy, M.C. 2001. Reproductive loss in high-producing dairy cattle: where will it end? Journal of Dairy Science 84:1277–1293.
14 Van Raden, P.M. and Sanders, A.H. 2003. Economic merit of crossbred and purebred US dairy cattle. Journal of Dairy Science 86:1034–1044.
15 Heims, B.J., Hansen, L.B., and Seykora, A.J. 2006. Fertility and survival of pure Holsteins versus crossbreds of Holstein with Normande, Montbeliarde, and Scandinavian Red. Journal of Dairy Science 89:4944–4951.
16 Kolver, E. and de Veth, M. 2002. Prediction of ruminal pH from pasture-based diets. Journal of Dairy Science 85:1255–1266.
17 Westwood, C.T., Bramley, E., and Lean, I.J. 2003. Review of the relationship between nutrition and lameness in pasture-fed dairy cattle. New Zealand Veterinary Journal 51:208–218.
18 Garrett, E.F., Pereira, M.N., Armentano, L.E., Nordlund, K.V., and Oetzel, G.R. 1999. Diagnostic methods for detecting subacute ruminal acidosis in dairy cattle. Journal of Dairy Science 82:1170–1178.

Renewable Agriculture and Food Systems: 24(1); 19–24 doi:10.1017/S174217050800238X

Integration of *Trichogramma ostriniae* releases and habitat modification for suppression of European corn borer (*Ostrinia nubilalis* Hübner) in bell peppers

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Accepted 30 July 2008 **Preliminary Report**

Abstract

A two-year field study was conducted to evaluate the effectiveness of *Trichogramma ostriniae* Pang et Chen (*T.o.*) releases in combination with habitat modification, to enhance biological control of European corn borer (ECB), *Ostrinia nubilalis* Hübner, the key pest of bell peppers in Kentucky. A randomized block design with a split-plot treatment arrangement was used in both years. Buckwheat, *Fagopyrum esculetum* Moench, was inter-planted as a nectar source for the wasps and as an attractant for ECB natural enemies. Sentinel ECB egg masses were placed in each subplot to monitor establishment and dispersal of *T. ostriniae* within and between plots. Fruit were harvested at maturity, graded according to USDA standards, inspected for insect damage, and dissected to confirm ECB presence when evidence of entry was suspected, to determine percentage of infested fruits. Percent ECB infested fruit was reduced in plots with wasp releases and in plots with buckwheat inter-planted. The interaction of habitat modification and wasp releases significantly reduced pepper damage as a result of the synergy between tactics. Percentage of *T. ostriniae* parasitized sentinel eggs was significantly higher in wasp release plots compared to non-release plots. *T. ostriniae* releases used in conjunction with habitat modification for ECB control in bell peppers appears to be a promising alternative to traditional insecticide-based strategies for small-acreage and organic farms. This study displays an example system utilizing conservation biological control at a landscape level for pest suppression.

Key words: integrated pest management, natural enemies, *Trichogramma ostriniae*, habitat modification, *Ostrinia nubilalis*

Biological control of European corn borer (ECB) (*Ostrinia nubilalis* Hübner) using *Trichogramma ostriniae* Pang et Chen has been successful in both field and sweet corn, as well as several solanaceous crops[1]. ECB is the primary pest of bell peppers in Kentucky and is traditionally managed with insecticide sprays. Recently, *T. ostriniae* was introduced from China as part of an effort to establish natural enemies of *O. nubilalis*, as this wasp is a native egg parasitoid of the Asian corn borer, *Ostrinia furnacalis* (Guenee)[1–4]. Studies investigating both inoculative and inundative releases of this wasp have resulted in 70–90% parasitism of ECB eggs[2].

Pepper plants receive little harm from first-generation ECB which occurs prior to setting fruit, although some damage is occasionally reported to stems or branches when the first generation is very large. However, second-generation larvae of ECB emerge from eggs and may feed very briefly on leaves before tunneling into the fruit of the pepper plant. Entry holes may be difficult to see, but are often marked with brown excrement and typically only fruits that are larger than one inch in diameter are attacked. Once the larva bores into the fruit, it is no longer acceptable for market. The larvae also cause physical damage, which results in premature ripening and entry points for several pathogens[5].

Agricultural landscapes rarely provide adequate resources to fully utilize existing natural enemies as a result of frequent management disturbances (herbicides, tillage, etc.) and predominance of monocultures in much of commercial agriculture[6]. The addition of key flowering plants to diversify a crop system is intended to provide supplemental resources to natural enemies through pollen and floral nectar, which contains sugars, proteins, amino acids, lipids,

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and other important nutritional substances[7]. Conservation practices, such as habitat modification to favor natural enemies of crop pests, can be implemented by integrating resources into the landscape in a way that is spatially and temporally favorable to natural enemies and practical for producers to implement[6,8]. The goal of habitat modification is to create a more favorable environment for natural enemies by providing such resources as: food for adult natural enemies, alternative prey or hosts, nesting sites and shelter from adverse conditions[6]. Specifically, buckwheat has shown effectiveness in attracting beneficial insects into cropping systems implementing biological control practices[9].

Adult *Trichogramma* wasps require food as adults[10] and the absence of specific nutrients can cause premature death and decrease the reproductive capacity of the wasps[11]. Nectar, honeydew, and host fluids are sources used by *Trichogramma* adults in the field[12]. Gurr et al.[13] believe that habitat manipulation, such as interplanting or use of groundcovers may introduce important ecological requirements for *Trichogramma*. The need for within-crop nectar sources for *Trichogramma* wasps may be of importance because of their small size and weak flight capabilities. Also, providing a food source may reduce the time in which adults are searching for food, thus increasing the amount of time available to search for hosts. Gurr and Nicol[14] suggest that because *Trichogramma* are proovigenic, food availability will not likely increase fecundity. They noted that by providing food during days 3–5 after first emergence, the lifespan of the wasps was increased from 8 to 13 days allowing them time to locate more host eggs to parasitize.

Releases of *T. ostriniae* for ECB control in bell peppers had been evaluated in 2002 and 2003; replicated trials were performed at several locations in and near Lexington, KY. Three releases at a rate of 370,000 *T. ostriniae* ha^{-1} were made in each release plot, resulting in significantly lower percentages of ECB infested fruits in release plots (1.5%) compared to non-release plots (5.2%)[15]. Trials in Virginia and Pennsylvania reported a 1.9% egg parasitism rate in non-release plots with 27.3% damaged fruit, compared to 48.7% egg parasitism and 8.7% damaged fruit in the release plots with four releases of 30,000–50,000 *T. ostriniae*/ 0.02 ha throughout the second-generation flight of ECB[1].

Previous research has shown that *T. ostriniae* wasps tend to prefer to search in plant architecture similar to that of corn[1]. The possibility of dispersal to nearby plants and away from bell peppers provided the impetus for the specific plot design used in this study. Thus a mixed cropping system model, incorporating sweetcorn adjacent to peppers, was incorporated into the design of this experiment. This is very similar to many small vegetable farms in the mid-south and southern Midwest. The objective of this study was to evaluate the use of *T. ostriniae* for ECB control in bell peppers using inundative releases in combination with interplantings of a nectar source as a habitat modification in a mixed cropping system.

Materials and Methods

This study used a randomized complete block experimental design with a split-plot treatment arrangement. There were five replicates with two main-plot treatments per replicate and two split-plot treatments within each main plot. Blocks were pairs of experimental units or treatment plots, within a pair the distance was at least 1000 feet between each plot, with larger distances used among blocks for isolation. Locations for the study included both University of Kentucky research farms in Lexington, Kentucky. In 2005, the South Research Farm supported one replicate and the North Research Farm held the remaining four replicates. In 2006, all five replicates were located at the North Research Farm.

A bacterial-spot resistant bell pepper cultivar, 'Aristotle', was used for all plots for both years to reduce the need for bactericide sprays. Plants were started in the greenhouse at the South Farm and transplanted into raised beds with black plastic mulch and drip irrigation at each location. Beds were 1.8 m from center-to-center with two rows of 35 pepper plants each. Plants were set using a water-wheel setter with 30.5 cm spacing between plants and rows.

Main-plot treatments tested the effect of *T. ostriniae* releases, while habitat modification was evaluated in the subplots. Each main plot consisted of either a non-release or *T. ostriniae* wasp release treatment. Each main plot was divided into two subplots consisting of no habitat modification (peppers only) and habitat modification with buckwheat (*Fagopyrum esculentum* Moench) in addition to peppers. Main plots in each replicate are separated by at least 305 m to reduce wasp dispersal into non-release plots and release plots were located downwind from non-release plots when possible. In both years, one replicate at North Farm was separated by only 183 m due to spatial limitations.

Each main plot consisted of two pepper subplots separated by 16 rows of sweet corn in the center and bordered with four additional rows of sweetcorn on each end of the plot. The addition of sweet corn provides a model for increased crop diversity that is typical of small acreage and organic farms in Kentucky.

Each pepper subplot contained five beds of peppers with one subplot supplemented with flowering plants (habitat modification treatment) at end of each pepper row and the other subplot without the supplemental flowering plants. Buckwheat (*F. esculentum* Moench), the habitat modification, was planted at each end of each raised bed of pepper plants as a potential nectar source for *T. ostriniae* in release plots and to attract beneficial insects. Approximately ten buckwheat seeds were directly planted into each of the three empty holes left by the water-wheel setter immediately adjacent to the final pepper plants at each end of each row. The buckwheat was provided the same irrigation and fertigation applications as the pepper plants. The same numbers of pepper plants were used in subplots with and without the habitat modification treatment. The buckwheat

flowered continuously from several weeks prior to *T. ostriniae* releases until several weeks after the final release, providing nectar resources throughout the release and post-release periods for *T. ostriniae*.

T. ostriniae used in the study were obtained from Cornell University, Ithaca, NY, USA. They were shipped overnight in parasitized *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs on cards divided for each subplot. Each card contained approximately 16,000 parasitized eggs and each subplot received one card per release. The release rate was approximately 1,160,000 *T. ostriniae* per hectare per release in both years with a total release of 4,640,000 *T. ostriniae* ha^{-1} for 2005 and 5,800,000 *T. ostriniae* ha^{-1} in 2006. Cards were placed in the center of the middle row of the subplots enclosed in 15 cm × 2.5 cm Petri dish cages with 0.8 mm mesh to allow for emergence while protecting the *T. ostriniae* from predation. Release dates were established according to a degree-day model predicting egg laying of second-generation ECB[16]. Initial releases began near the degree-day target for initiation of second-generation ECB egg laying. Additional releases were made in coordination with the degree-day target for 25 and 75% completion of egg laying, with an additional release to target egg laying by third-generation ECB.

Sentinel ECB egg masses were provided by the USDA Corn Insects and Crop Genetics Research Laboratory at Iowa State University. Ten egg masses on wax paper were stapled to the underside of pepper leaves at regular intervals on the border rows of each subplot in both the non-release and release plots. The egg masses were in place at the time of each *T. ostriniae* release and collected within 48–72 h. To check for residual parasitoid activity from 2005, egg masses were set out in 2006 prior to the first *T. ostriniae* release date. Sentinel egg masses were used to determine percent parasitism at each location, monitor for *T. ostriniae* movement to non-release plots, assess overwintering *T. ostriniae* success with a prerelease sample in the second year, and indicate if any other *Trichogramma* species were present. The egg masses were collected from the field and placed in gelatin capsules and stored for later observation. Percent parasitism was established for the sentinel eggs using a dissecting microscope to look for characteristic discoloration of parasitized eggs.

Yellow sticky card traps (Gemplers 6" × 12" Sticky Cards 2005. IPM Laboratories, Inc. Locke, NY, USA) were attached horizontally to a 1 m pole and placed in the center of each subplot to give an indication of what types of insects were present in each plot and to determine if the habitat modification treatment increased abundance of beneficial insects. Cards were placed in the plots for two-week intervals and replaced with new cards at the time of removal. Upon removal from the field, sticky cards were stored at room temperature and wrapped in wax paper for protection until evaluation. Cards were removed from wax paper for identifications to the family level.

Fruit were harvested at maturity multiple times from the inner three beds of each subplot. Peppers were separated into marketable and unmarketable fruits according to USDA grading standards of shape, size, and quality[17]. All fruit were examined for evidence of insect frass around the stem cap and insect tunneling in the walls. Those with signs of damage were kept separate and later dissected to determine if the damage was due to ECB. Both marketable and unmarketable fruits were weighed and only marketable fruits were counted and graded as medium, large, and extra-large fruits according to the USDA standards. Harvest dates varied by replication each year, due to fruit set, maturity differences, and the availability of labor, but all plots within a single replicate were harvested on the same day. Two harvests were made in each year of the study with approximately 4–6 weeks between harvests.

Percentages of infested fruits were compared to evaluate the effect of wasps and habitat modification, and the effect of combining wasps and habitat modification. The data were subjected to analysis of variance (ANOVA) tests and the arc sine of the square root transformation was used to analyze percentage of infested fruits (SAS Institute Inc., Cary, NC, USA). Sentinel egg parasitism was analyzed using ANOVA using the same transformation and a weight statement to adjust for the number of missing egg masses. Percent missing sentinel egg masses was evaluated using ANOVA. Data collected from the yellow sticky card traps were analyzed using ANOVA. Data were pooled across years due to the lack of significance when analyzed separately by individual years.

Results

ECB sentinel egg parasitism

Combining data from both years, there were significantly more parasitized eggs found in release plots (4.4%) compared to non-release plots (0.3%) ($F = 276.3$; $df = 1.9$; $P = < 0.01$). Egg parasitism was similar in plots with the habitat modification compared to those without ($F = 3.15$; $df = 1.9$; $P = 0.08$), and there was no significant interaction of the two treatments ($F = 2.4$; $df = 1.9$; $P = 0.13$). The combination of the two treatments resulted in 5.4% parasitized eggs compared to 0.2% for those without either treatment applied (Table 1). A large number of missing egg masses occurred throughout the study due to predation and rainfall. Percentage of missing egg masses was accounted for by using a weighted analysis for percent parasitism using the number of remaining eggs as the weighting factor.

Predator insect densities

An array of insects were recorded from the yellow sticky cards, but only those predators with host feeding strategies associated with *Ostrinia nubilialis* were used in the statistical analysis. Families evaluated included: Coccinellidae, Nabidae, Reduviidae, Syrphidae and Anthocoridae. All families are predaceous on ECB eggs, whereas Syrphidae and Anthocoridae may also feed on early instar larvae[2]. The sticky card trap counts were analyzed across

Table 1. Average yields, percent ECB infested fruit and average number of ECB infested fruit (SEM), 2005–2006.

Treatment	% ECB sentinel egg parasitism	ECB infested fruit	
		%	No. per ha
No *T. ostriniae* release	0.3 (0.2)	3.5 (0.2)	5332 (1048.3)
T. ostriniae release	4.4[1] (0.7)	2.4[1] (0.2)	3366[1] (637.3)
No habitat modification	1.5 (0.6)	3.2 (0.2)	4737 (963.3)
Habitat modification	2.3 (0.9)	2.6[1] (0.2)	3961[1] (814.3)
No *T. ostriniae* release + No habitat modification	0.2 (0.2)	3.6 (0.3)	5812 (1660.6)
No *T. ostriniae* release + Habitat modification	0.3 (0.3)	3.4 (0.3)	4851 (1353.1)
T. ostriniae release + No habitat modification	3.5 (0.8)	2.9 (0.3)	3660 (950.1)
T. ostriniae release + Habitat modification	5.4 (1.0)	1.9[1] (0.2)	3071 (890.4)

[1] ANOVA indicated significant differences for *T. ostriniae* releases versus no releases for the percentage of ECB sentinel egg parasitism ($P \leqslant 0.05$). ANOVA indicated significant differences due to *T. ostriniae* releases and habitat modification for percent ECB infested fruit ha^{-1} and number of ECB infested fruit ha^{-1}. Significant differences were indicated for *T. ostriniae* and habitat modification interaction for percentage of ECB infested fruits ($P \leqslant 0.05$).

Table 2. Predaceous insect trapping: average number of insects per family on yellow sticky cards (SEM), 2005–2006[1].

Treatment	No. Coccinellidae	No. Nabidae	No. Reduviidae	No. Syrphidae	No. Anthocoridae
No *T. ostriniae* release	9.9 (3.1)	1.3[2] (0.3)	0.4 (0.2)	3.9 (1.1)	1.2 (0.4)
T. ostriniae release	6.7 (1.1)	0.2 (0.1)	0.2 (0.1)	2.0 (0.3)	0.8 (0.3)
No habitat modification	6.8 (1.1)	0.5 (0.2)	0.3 (0.1)	3.4 (1.0)	1.0 (0.3)
Habitat modification	9.8 (3.1)	1.0 (0.3)	0.35 (0.2)	2.5 (0.7)	1.0 (0.4)
No *T. ostriniae* release + No habitat modification	6.0 (1.1)	0.9 (0.4)	0.3 (0.2)	4.4 (1.9)	1.1 (0.4)
No *T. ostriniae* release + Habitat modification	13.8 (6.0)	1.6 (0.5)	0.5 (0.3)	3.4 (1.3)	1.2 (0.7)
T. ostriniae release + No habitat modification	7.5 (2.0)	0.1 (0.1)	0.2 (0.1)	2.3 (0.6)	0.8 (0.4)
T. ostriniae release + Habitat modification	5.8 (1.0)	0.3 (0.2)	0.2 (0.1)	1.6 (0.3)	0.8 (0.4)

[1] Traps in place for two-week periods—2005: (26 August–23 September); 2006: (17 August–14 September).
[2] ANOVA indicated significant differences for number of Nabidae in *T. ostriniae* release versus non-release plots ($P \leqslant 0.05$).

the two-year study due to low insect densities when analyzed independently for each year. No statistical differences were found among insects evaluated for the habitat modification treatment compared to the no habitat modification treatment. A significant treatment effect was found for Nabidae in non-release plots (1.3 insects per card) compared to release plots (0.2 insects per card) ($F = 8.8$; $df = 1.9$; $P = 0.02$). Means for all insects evaluated, except Syrphids, tended to be higher in habitat modification plots compared to no habitat modification plots, although not significantly higher (Table 2). This significant treatment effect is likely due to a Type 1 statistical error.

Percentage of ECB infested fruit

When data were combined across the two-year study, a significantly lower percentage of infested fruit was found in *T. ostriniae* release plots (2.4%) compared to non-release plots [3.5% ($F = 5.2$; $df = 1.9$; $P = 0.05$)], and in habitat modification plots (2.6%) compared to non-habitat modification plots [3.2% ($F = 10.4$; $df = 1.9$; $P = 0.01$)], and a significant interaction observed, with 1.9% damaged fruit with the treatment combination compared to 3.6% with no treatments applied [$F = 4.8$; $df = 1,9$; $P = 0.06$ (Table 1)].

Discussion

ECB sentinel eggs

Significant differences in parasitism of sentinel eggs in plots with *T. ostriniae* releases were expected compared to those not receiving *T. ostriniae* releases. The effect of habitat modification was not significant for a treatment effect or a treatment interaction when data were analyzed with the study years combined. This may have been due to the sentinel eggs being left in the field for only 2–3 days, just after the wasp releases. If the buckwheat in the habitat modification and wasp release treatment combination was providing a needed food source to extend the life span of adult wasps, it is unlikely that the sentinel egg parasitism

levels would have differed significantly from that of the wasp release only treatment, as *T. ostriniae* wasps should survive the duration of the sentinel egg placement periods without supplemental nutrition. Due to the length of time the sentinels were in the field, the benefit of habitat modification on *T. ostriniae* parasitism or lifespan would not be detected unless an additional set of sentinel eggs were in place after the initial set.

The percentages of ECB sentinel eggs parasitized by *T. ostriniae* in this study were lower than those reported in previous studies. An average parasitism rate between 4 and 6% when the treatments were combined is considerably lower than those reported in trials by Kuhar et al.[1] (48.7%) and Friley[15] (14.9–15.3%). It is likely the reduction in sentinel parasitism is a result of dispersal away from the peppers and into the adjacent corn, as well as using slightly lower release rates than the Kuhar et al.[1] study. It has been established in the previous work that *T. ostriniae* prefers to search in corn rather than peppers for ECB eggs[1]. Although parasitism is lower in this study, the levels observed in this study may be more representative of bell pepper crops that are located on farms displaying high crop diversity.

The sentinels were placed in the field on a wax paper substrate and attached to the plant using staples. These egg masses were approximately 2 days old when placed in the field and remained in the field for a relatively short (48–72 h) period. Sentinel eggs were not protected by mesh as this may have lowered the parasitism by *T. ostriniae*, however, it did expose the eggs to predation. The artificial nature of the sentinel egg mass placement is likely to underestimate the actual level of *T. ostriniae* parasitism of wild ECB egg for several reasons. *T. ostriniae* may preferentially parasitize ECB egg masses oviposited on plants that appear more natural and/or fresher. Fresher egg masses may have higher release rates of volatile chemicals to attract *T. ostriniae* and other natural enemies. The wasps also have less time to encounter the sentinel egg masses prior to removal from the field compared to wild ECB eggs. However, the value of the sentinel egg mass data is to provide a relative index to measure differences and compare *T. ostriniae* activity among treatments, rather than providing a measure of actual parasitism levels by *T. ostriniae*.

Predator insect densities

The insect density data obtained from the sticky card traps may not have been statistically significant, but the means show consistently higher numerical natural enemy densities in plots with the habitat modification treatment compared to those without habitat modification. This method of data collection is not suitable for adequately gauging the population levels of these insect taxa throughout the entire plot, only in the center of the plot, the greatest distance from the buckwheat plants. The results of the sentinel egg mass data, combined with the reduction in percentage of infested fruits in plots with buckwheat, indirectly indicate the habitat modification treatment likely aids in attracting and retaining predatory insect populations. Increased replications of sticky card traps, used in conjunction with other sampling techniques throughout the season or placement closer to the buckwheat plants, would be expected to indicate higher population levels in both the habitat modification alone treatment and those plots containing the treatment combination, based on fruit damage data. It is also possible that the buckwheat affected other natural enemies that are not readily sampled through the use of yellow sticky cards.

Additionally, the habitat modification treatment was applied to the border of the research plots at the ends of the double rows of peppers. Based on the numbers of beneficial insects found within the plots, an alternate amount and arrangement of buckwheat may be superior to that used here. Further research into the optimal arrangement of habitat modification is suggested, as well as the examination of other potential flowering plants that may benefit the *T. ostriniae* as a food source and refuge and attract beneficial insects into the cropping system. It is possible that interspersing the flowers throughout the field will have the greatest benefit to the wasps and likely disperse natural enemies more efficiently.

ECB infested fruit

The percentage of ECB infested fruit followed similar trends for both treatments and the treatment combinations and will be combined for discussion. When the data were combined across the two-year study, both treatments and the treatment interaction had a significant effect on the reduction of ECB infested fruit. There was 5% less infested fruit per hectare with just the habitat modification treatment applied, a 19% reduction of ECB percent infested fruit using only *T. ostriniae* releases, and a 47% reduction when the treatments were combined (Table 1). The 5% reduction can be attributed to the effect of other natural enemies attracted to the habitat modification plots in the absence of *T. ostriniae*. These results indicate the tactics are compatible with one another and that the *T. ostriniae* and habitat modification treatments are interacting synergistically when combined to reduce ECB damage. The large synergistic reduction in damaged fruit observed when habitat modification is combined with *T. ostriniae* releases is likely due to enhancement of the wasps by the buckwheat.

When comparing this study to other published studies using *T. ostriniae* for ECB control in bell peppers, the reductions presented here are considerably lower. Friley[15] demonstrated a 71% reduction in ECB infested fruit and Kuhar et al.[1] a 68% reduction. This study utilized sweetcorn to isolate plots and simulate more diverse cropping systems; the previous studies were more typical of monoculture production systems. The results of this study are likely to be more applicable to small acreage and organic operations in which a diversity of cropping systems

would be located adjacent to one another in a polyculture arrangement. Previous research has shown that *T. ostriniae* wasps tend to prefer plant architecture similar to that of corn[1]. The 19% reduction of ECB infested fruit using *T. ostriniae* wasp releases alone and then a 47% reduction when combined with the habitat modification suggests that dispersal of *T. ostriniae* away from the bell peppers may be occurring without habitat modification, particularly in consideration of higher parasitism levels observed in previous studies[1,15]. The percent reduction of infested fruits was significant with the treatments combined and may hold promise as a feasible management tactic for operations exhibiting high plant diversity. However, the success of these tactics has not been thoroughly examined under a variety of field conditions or landscape designs. This study utilized a design with spacing of buckwheat at regular intervals between every 35 pepper plants, but it is unknown if a better arrangement around or in pepper fields exists. Future research could focus on the arrangement of flowering plants to optimize the control exhibited by *T. ostriniae* in an attempt to negate any loss of control due to preferential dispersal away from peppers in a mixed cropping system. Furthermore, this study may be used as an example for other agro-ecosystems that have the potential to utilize conservation biological control on a landscape level as an alternative to pesticide-based management practices. Tscharntke et al.[18] point out that enemy communities in managed systems are less diverse than those in natural systems, thus emphasizing the importance of plant diversity on enemy populations. The addition of nectar resources to the crop system is just a single example of the benefits that can be attained by converting a managed system to a more diverse landscape, thus promoting a more diverse population of natural enemies in pest suppression.

Acknowledgements. The authors would like to recognize Darrell Slone, Katie Bale, and the South Farm seasonal workers for their help with the field work for this research, as well as Kenneth Yeargan and John Obrycki for their revisions and comments on this paper. This study was funded with a grant through a USDA Initiative for Future Agricultural and Food Systems grant. This paper is no. 07-08-051 of the University of Kentucky Agricultural Experiment Station.

References

1 Kuhar, T.P., Barlow, V.M., Hoffman, M.P., Fleischer, S.J., Groden, E., Gardner, J., Hazzard, R., Wright, M.G., Pitcher, S.A., Speese, J. III, and Westgate, P. 2004. Potential of *Trichogramma ostriniae* (Hymenoptera: Trichogrammatidae) for biological control of European corn borer (Lepidoptera: Crambidae) in solanaceous crops. Journal of Economic Entomology 97:1209–1216.

2 Wang, B., Ferro, D.N., and Hosmer, D.W. 1997. Importance of plant size, distribution of egg masses, and weather conditions on egg parasitism of the European corn borer, *Ostrinia nubilalis* by *Trichogramma ostriniae* in sweet corn. Entomologica Experimentalis et Applicata 83:337–345.

3 Hoffmann, M.P. 2005. Biological control: a guide to natural enemies in North America. *Trichogramma ostriniae* Pang et Chen Hymenoptera: Trichogrammatidae. Cornell University. Available at Web site http://www.nysaes.cornell.edu/ent/biocontrol/parasitoids/trichogramma_ostriniae.html.

4 Pang, X.F. and Chen, T.L. 1974. *Trichogramma* of China (Hymenoptera: Trichogrammatidae). Acta Entomologica Sinica 17:441–454.

5 Bessin, R., Welty, C., and Sparks, A. 2005. Peppers and eggplant. In R. Foster and B.R. Flood (eds). Vegetable Insect Management. Meister Media Worldwide, Willoughby, OH. p. 142–154.

6 Landis, D.A., Wratten, S.D., and Gurr, G.M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology 45:175–201.

7 Vattala, H.D., Wratten, S.D., Phillips, C.B., and Wackers, F.L. 2006. The influence of flower morphology and nectar quality on the longevity of a parasitoid biological control agent. Biological Control 39:179–185.

8 Gurr, G. and Wratten, S.D. 1999. Integrated biological control: a proposal for enhancing success in biological control. International Journal of Pest Management 45:81–84.

9 Berndt, L.A., Wratten, S.D., and Hassan, P.G. 2002. Effects of buckwheat flowers on leafroller (Lepidoptera: Tortricidae) parasitoids in a New Zealand vineyard. Agricultural and Forest Entomology 4(1):39–45.

10 Andow, D.A. and Risch, S.J. 1987. Parasitism in diversified agroecosystems: phenology of *Trichogramma minutum* (Hymenoptera: Trichogrammatidae). Entomophaga 32:255–260.

11 Hegazi, E.M., Khafagi, W.E., and Hassan, S.A. 2000. Studies on three species of *Trichogramma*. I. Foraging behaviour for food or hosts. Journal of Applied Entomology 124:145–149.

12 Zhang, G., Zimmerman, O., and Hassan, S. 2004. Pollen as a source of food for egg parasitoids of the genus *Trichogramma*. Biocontrol Science and Technology 14(2):201–209.

13 Gurr, G., Wratten, S.D., and van Emden, H.F. 1998. Habitat manipulation and natural enemy efficiency: implications for the control of pests. In P. Barbosa (ed.). Conservation Biological Control. Academic Press, San Diego. p. 155–183.

14 Gurr, G. and Nicol, H. 2000. Effect of food on longevity of adults of *Trichogramma carverae* Oatman and Pinto and *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae). Australian Journal of Entomology 39:185–187.

15 Friley, K.L. 2004. Biological control of the European corn borer, *Ostrinia nubilalis*, by inundative releases of the parasitic wasp, *Trichogramma ostriniae* in bell peppers. MS thesis, University of Kentucky.

16 Brown, G.C. 1982. A generalized phonological forecast model for European corn borer. Journal of Kansas Entomology Society 55:625–638.

17 United States Department of Agriculture (USDA) 2005. United States Standards for Grades of Sweet Peppers.

18 Tscharntke, T., Bommarco, R., Clough, Y., Crist, T.O., Kleijn, D., Rand, T.A., Tylianakis, J.M., Nouhuys, S.V., and Vidal, S. 2007. Conservation biological control and enemy diversity on a landscape scale. Biological Control 43:294–309.

Renewable Agriculture and Food Systems: 24(1); 25–37 doi:10.1017/S1742170508002366

Farm structural change of a different kind: Alternative dairy farms in Wisconsin—graziers, organic and Amish

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Accepted 24 June 2008; First published online 9 December 2008 **Research Paper**

Abstract

Although the emergence of large confinement operations out of a system previously dominated by mid-sized confinement has been one major structural trend in Wisconsin dairy farming since the 1990s, a second structural trend has been the significant emergence of moderate-sized dairy farms using alternative management strategies: management-intensive rotational grazing (MIRG) (25% of Wisconsin's dairy farms), organic production (3%) and Amish farm production practices (5–7%). This paper presents the first systematic and representative comparative study on the structure, behavior and performance of multiple pasture-based dairy farm strategies. Wisconsin is an ideal site for this study given the prevalence of pasture-based farms, yet many of the findings here should be relevant for other traditional dairy states where similar types of alternative farm management systems are also emerging. Divergence with respect to farm strategy has implications for structure, technology and management adoption patterns as well as farmer satisfaction levels. Our findings suggest that alternative dairy farming systems are likely to become more prevalent on the agricultural landscape of Wisconsin.

Key words: dairy structure, industrialization, divergence, Amish, organic farming, pasture dairy, intensive grazing

Introduction

The rapid growth of large-scale 'industrial' farms in the US dairy sector in recent decades has been well documented[1–6]. However, this 'industrialization' trend is neither universal in the present nor inevitable in the future[7–9]. Although large dairies (those with herd sizes over 200 cows) produce over half of the nation's milk; 90% of the nation's 75,140 dairy farms have herds with fewer than 200 cows[10] and most of these small- to moderate-scale dairy farms are concentrated in the traditional dairy states: Wisconsin, Minnesota, Ohio, Pennsylvania, Michigan and New York[1]. With 12,000 operations of less than 100 cows, Wisconsin—'America's Dairyland'—had about a quarter of the nation's operations of this size category[4,10]. These smaller-sized farms are more predisposed to adopt alternative production and marketing strategies which have become much more common since the mid-1990s[11,12]. We examine the divergence in structure and strategy that occurrs in the United States dairy sector by looking closely at the rapid growth of alternative dairy farms in Wisconsin.

Our examination compares the structure, behavior and performance of five distinct dairy farm management systems in Wisconsin. These systems include large-scale confinement (over 200 cows) and traditional semi-confinement (under 200 cows) as well as three pasture-based management systems which have become important in recent decades. The largest (in terms of farm numbers) of these three systems is broadly identified as management intensive rotational grazing (MIRG), a strategy that is often characterized as 'low-cost' or 'low-input', because it relies substantively on intensive animal grazing rather than solely on forage and grain produced, mechanically harvested and physically delivered by the farmer or from other farms. This strategy has become quite widespread in a number of traditional dairy-producing states[13–16] and accounts for almost 25% of producers in Wisconsin. The second type of alternative dairy farm strategy is certified organic. These farms produce and market milk as free of agrichemicals and synthetic hormones, and their numbers have grown more than tenfold over the past decade[17,18]. They account for roughly 3% of the dairy farms in Wisconsin[19]. Organic

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dairy producers generally, but not always, overlap with the MIRG farms in their intensive use of rotationally grazed pasture as a feeding system. Amish dairy farms are the third farm type, which are also pasture-based though they often use extensive rather than intensive methods. They continue to have a strong presence on the agricultural landscape in well-established Amish communities like Pennsylvania, Ohio and Indiana[16,20]. But, in the past couple of decades, Amish dairy farmers have migrated to states with newer settlements often where non-Amish farmers are exiting farming, such as in Wisconsin, New York, Michigan and Missouri[5,9,21,22]. It is estimated that Amish farmers will be around 10% of Wisconsin's dairy sector by 2010[5]. Because of the very recent take-off in organic dairy farming, as well as the difficulty in identifying Amish farms from standard surveys, no systematic and representative comparisons exist of the structure, behavior and performance of these multiple alternative dairy farm strategies.

This paper provides that kind of analysis for Wisconsin, and in the process explores the basis for the continued persistence of small- to moderate-sized operators during an era of significant expansion in the number and scale of large confinement operations[4,6,23]. The first empirical section documents the recent divergence in the structure and management strategies on Wisconsin dairy farms. Next, the behavior of these farm strategies is explored by comparing and contrasting the management practices and technologies utilized. Finally, several social and economic performance indicators, including productivity, income and quality of life measures are compared.

Methods

The analysis primarily exploits data from two surveys done by the Program on Agricultural Technology Studies (PATS) at the University of Wisconsin, Madison. (Data used from outside sources will be cited as such.) Both surveys were conducted using a modified Dillman method[24]. In order to mitigate response bias, each non-respondent was contacted three times over a three-month period. Survey respondents included both confinement and pasture-based farmers. The three types of pasture-based farmers are MIRG, organic and the Amish. Confinement operations are also included mainly for comparison purposes. Both surveys are supplemented with results from selected on-farm interviews, which were conducted by the lead author.

(1) The first survey includes a random sample of the entire state dairy sector conducted in the winter of 2003. The statewide dairy survey generated over 700 usable surveys and had a 45% response rate. One hundred and sixty-four (MIRG) farmers and 491 confinement farmers responded to this 2003 Wisconsin Dairy Farm Poll. Please note that a random sample component of a survey from the winter of 2005 is also utilized to a limited extent in the analysis below. The 2005 survey was done with some assistance from PATS by an affiliated institution, the Center for Integrated Agricultural Systems, with the explicit purpose of examining various measures of quality of life on different types of dairy farms. Many questions on this 2005 survey are identical or overlap closely with those on the 2003 Dairy Farm Poll which made robust comparisons possible. Because organic and Amish dairy farmers were not separately identified or significantly represented in the random sample component of the 2005 data, information is only available on the MIRG and confinement groups.

(2) The second survey undertaken in the spring of 2004 focused on two alternative dairy farm groups: a sample of Amish farmers from Old Country Cheese, an Amish cheese cooperative based in Cashton, WI, and a statewide sample of organic dairy farmers (members of Organic Valley and Midwest Organic Services Association organic certified operators). This survey also had a 45% response rate, with 100 Amish and 85 organic producers responding to the survey.

To test the statistical significance of differences in behavior and performance across the different farming systems, we use standard *t*-tests with a 95% confidence interval cut-off. These are denoted in the tables by letters (i.e. Amish = a, organic = b, MIRG = c and confinement = d). Some of the tables also include a comparison with medium-sized confinement (under 200 cows = e) and large-scale confinement (over 200 cows = f). For example, the 'b' for a given number or percent in the first column of a table denotes that there is a statistically significant difference between that outcome and the outcome in column b.

Divergence in Dairy Farm Structure and Management Strategies

Twenty years ago, the structure of dairy farming in America's dairyland was relatively homogeneous. Almost all farms utilized semi-confinement methods, where the vast majority of the feed was provided to cows in the form of forage and feed harvested mechanically and delivered to them in the barns. Pastures were used non-intensively, mostly for animal health purposes[25]. Stanchion and tie-stall barns were the predominant structures used as combined housing and milking facilities. Milking parlors were rare, there were only occasional organic dairy farms with no major market presence, and the Amish were just beginning to make serious inroads into Wisconsin agriculture. Increasing diversity in the past several decades can be seen first in terms of the changing size structure of the industry and second in the emergence from moderate-scale semi-confinement dairy farms to five distinctive dairy farming systems: large confinement (over 200 cows), moderate-scale confinement (under 200 cows), MIRG, organic and Amish. Please note that, according to our data, farms with herd sizes that are between 100 and 199 cows

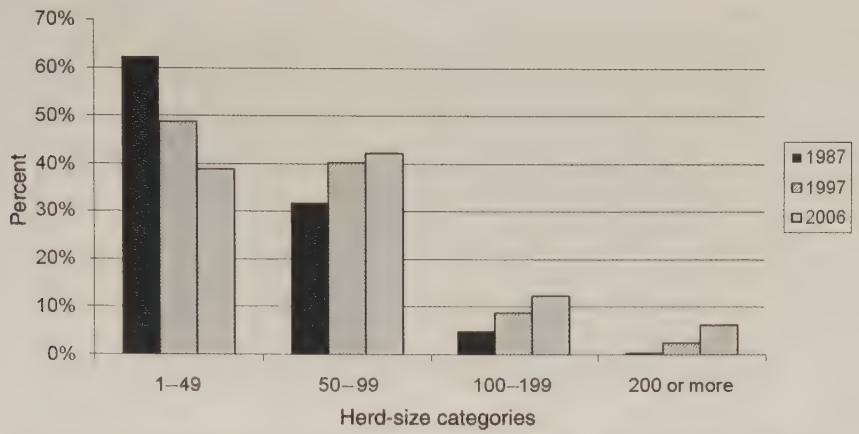

Figure 1. Percent of Wisconsin dairy farms by herd-size category 1987, 1997 and 2006. (Sources: 1987 (Total 36,459 farms) and 1997 (Total 21,997 farms), Census of Agriculture; 2006 (Total 14,900 farms), NASS-USDA.)

also have somewhat distinctive characteristics in terms of adoption of technologies and performance. Because the focus of the report is on the alternative farm strategies, we do not split confinement farms with herd sizes under 200 cows and thus treat these confinement farms as one category for the rest of this paper.

Although dairy processing and market structure are not the focus of this paper, it should be noted that there is more potential for product diversification in dairy than in other livestock sectors like poultry, where production is becoming extremely interconnected along with processing. Thus, there may be more possibilities of dairy farm-level adoption of alternative production practices than in other livestock sectors as these decisions have a lower likelihood of being constrained by concentrated marketing arrangements. For example, adopting alternative practices such as MIRG does not require alternative processing[26]. Diverse and unconstrained dairy product markets provide a promising economic environment for diverse types of farm operations[27].

Overall structural change

Divergence in the Wisconsin dairy sector in the past 20 years can be seen through the 1.6-fold decrease in the percent of farms with herds under 100 cows and the almost 10-fold increase in the percent of farms with herds over 200 cows. Nonetheless, in 2006, 81% of Wisconsin dairy farms were still under 100 cows and 94% were under 200 cows, in contrast to western states like California where 89% of herds were larger than 500 cows; herd sizes smaller than 200 cows are moderate sized indeed. These Wisconsin moderate-sized farms produced 64% of the state's milk supply[10]. Divergence in the size and management structure in Wisconsin's dairy sector can be explained by changes amongst existing farmers as well as the characteristics of entering and exiting farmers. Many of the moderate-sized semi-confinement farms from the 1980s and 1990s have exited, which explains the decrease in dairy farm numbers from 36,500 in 1987 to 14,900 in 2006 (Fig. 1)[10,25]. About 500 of those confinement operations converted to large-scale confinement in the past couple of decades. The majority of expansions that led to this increase in large confinement dairy were due to incremental size changes, often followed by major expansions[6], and as a result it is likely, too, that many of the operations currently in the 100–199 size category could move in that direction. It is fair to say that an even larger number of the moderate-sized semi-confinement farms were converted to MIRG operations by existing operators or replaced by entering farmers utilizing MIRG or other alternative dairy farm systems, including around 700 farms that have been bought by Amish farmers in the past several decades.

Management structural divergence: MIRG farmers

The emergence of MIRG as a farm management strategy was a major trend in the 1990s in traditional dairy products producing states[13–16] that has seemed to plateau in recent years in Wisconsin. As seen in Figure 2, the percentage of MIRG farmers doubled from 7 to 14% in the four-year period from 1993 to 1997. It took another eight years for the percent of MIRG dairy farms to almost double again to 26% in 2005. It is important to note that the overall number of MIRG farms has not doubled twice since 1993 (when the total number would have been close to 2200, compared to just under 4000 in 2005), but that the MIRG strategy has become far more prevalent proportional to the conventional dairy farm strategy.

Historical accounts of the emergence of the MIRG farm strategy highlight the critical role that farmer to farmer information exchange played regarding how to manage pastures most efficiently in a localized area[28]. This localized information exchange was especially needed given that land-grant university pasture research and support declined significantly after 1950[29]. The clustering patterns of MIRG adoption in Wisconsin may be related to this information exchange and/or the nature of the unglaciated landscape where there are high rates of adoption.

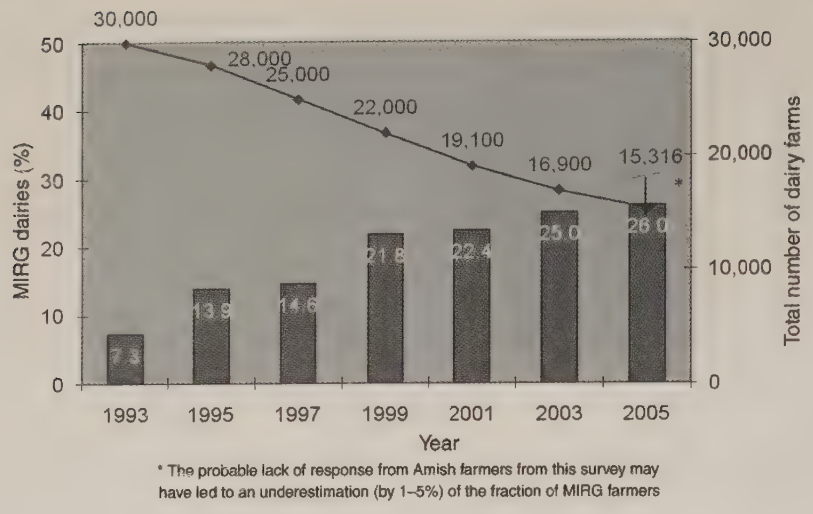

Figure 2. Use of management-intensive rotational grazing (MIRG).

The MIRG farm strategy is a combination of a very old technique involving heavy reliance on pasture[30] with more recent pasture management knowledge[28] aimed at making intensive use of the pastures. Technically, we define farmers as MIRG based on their reliance on pastures as a source of feed during the grazing season and by their movement of cows to a new paddock about once a week. In that sense, we use a relatively liberal definition compared to other works[14,31], but we consider variations on the definition from less to more intensive MIRG operations.

Management structural divergence: organic and Amish farmers

In recent years, it has become clear that significant structural divergence is also occurring within the pasture-based dairy farm strategies in the US, with Wisconsin being a prime site example of this structural change. The growth of MIRG farms overall may have reached a plateau at about 25% of the farms in Wisconsin, but the diversity within the MIRG farm strategy has increased. At present, Wisconsin provides an ideal context for exploring diversity in dairy farming and may be reflective of the rest of the Upper Midwest as both organic (i.e., third-party certified) and Amish farm numbers are increasing in Wisconsin, which impacts the dynamics of the MIRG farm strategy. Organic dairy farmers are a growing fraction of the MIRG farm numbers, constituting 1% of the graziers in 1997, 8% of the graziers in 2005 (calculations supplemented with data from ERS–USDA), and could account for 10–12% of graziers by the end of 2007[19]. The Amish were roughly 14% of Wisconsin MIRG graziers in 2002 (calculations supplemented with data from Cross[9])[22]. The Amish and organic farm types when combined constitute about one-fifth to one-fourth of MIRG farm numbers in the early 2000s, and this percentage will probably expand as these two farm types seem likely to grow at rapid rates in the near future. Both organic and Amish farmers are geographically clustered in similar areas where MIRG farmers overall are clustered[9,22].

Organic milk production began to take off in the 1990s, and has the fastest growing dairy product sales, with demand far exceeding the supply most of the time in the late 1990s and early 2000s. Some trade journals link the approval in 1993, and subsequent use, of the controversial hormone, rBST, as a primary reason why consumers, demand for organic milk grew rapidly in the 1990s[32]. Organic-dairy cow numbers in the US have grown from about 2000 in 1992 to 86,000 in 2005[19] to well over 100,000 by the end of 2007. Organic farming is also seen as a promising alternative towards the goal of keeping smaller scale farms operating, particularly in the Midwest and in the Northeast (i.e. traditional dairy producing states)[18,33]. Wisconsin is the leading producer of organic dairy products in US markets and home base to the largest organic milk cooperative, Organic Valley (CROPP), which now has members in 29 states. Organic dairy farm numbers in Wisconsin have grown from approximately 54 farms in 1997 to over 350 farms in 2005 (calculated from USDA–ERS data)[19] and probably well over 400 by the end of 2007.

Amish dairy farms comprise roughly one-eigth of all dairy farms in the US, as estimated by US Farm Service Agency officials in 2005[5]. The Old Order Amish dairy operations are an independent phenomenon from the other alternative groups (organic and MIRG overall) as this farm type is defined by their Anabaptist Christian religious and cultural identity. For the Amish, 'living in a redemptive community, separated from the world, is essential to salvation'[21]; as exemplified by one Wisconsin Amish farmer interviewee who stated 'confess[ing] Christ with our farm' was the primary motive for farming. The geographic areas that have the highest concentration of farms with the smallest dairy herds correspond well to maps where there are dense concentrations of Amish dairy farms in states like Wisconsin, Iowa, Indiana, Ohio and Pennsylvania, and Missouri and Kentucky. Some of the states with really high percentages of Amish dairy farms

include Indiana, with three-fifths of dairy farms being Amish owned, and Pennsylvania and Ohio where over one-fourth of the farms are Amish owned[5].

Many Amish who have a desire to farm as a way to maintain religious and family values have migrated from eastern urbanizing states to other states like Wisconsin with more available farm land. Amish-owned dairy farms constituted roughly 5% of the dairy sector in 2004[26] and were estimated to be around 10% of the state's dairy numbers in 2007[5]. Wisconsin has the second largest concentration of Amish church settlements in the US[20]. Whereas only 22% of Wisconsin farms overall have dairy herds, the majority of Amish farmers in Wisconsin (80%) have dairy herds[9]. Amish dairy farms are occupying barns which would otherwise be abandoned or torn down as the number and proportion of non-Amish dairy farms decline rapidly[22].

Across the state, 18 settlements were founded between 1920 and 1990 that still exist today, and at least 21 more have been founded since that time[20]. Many of these settlements have been growing rapidly given the large family sizes and high retention rates to the Amish faith. The Kickapoo Valley settlements in this survey chose to start their own cheese co-op which would be committed to buying milk in cans. In contrast, some other districts in Wisconsin and from where the Amish emigrated chose to adopt bulk tanks and electrical means to cool milk several decades ago, partly out of the necessity of marketing their milk under increased regulatory structure[34]. The Amish dairy farmers surveyed for this paper also have some distinctive demographic characteristics, such as lack of schooling beyond the 8th grade. These dairy farmers have fewer years of farm operating experience than other dairy farmers, which may reflect their younger age (average age of an Amish is 41 years compared to an average of 48 years in the other types of farmers). A relatively small proportion of the Amish obtained their farm from their parents as many emigrated from other states. Amish farm-acquisition stands in contrast to the majority of dairy farmers in the other farming strategies examined here, where farm transfers from parents are common. Because the elevated price of agricultural land (reflecting residential and recreational demand) serves as a significant constraint to other new entrants in farming, the number of 'new' Amish farms is notable.

Alternative dairy farm herd sizes

The Amish farmers as well as the other pasture-based dairy farm types have average herd sizes which are much smaller than the Wisconsin dairy sector overall. The average herd size on the PATS sample of Amish-owned farms is 15 cows (median around 14) whereas the overall state Amish herd average is 19 cows[22]. MIRG farmers in this study have a mean average herd size of 48 (median 42), and organic dairy farms have an average herd size of 65 cows (median 47). At the other end of the spectrum, confinement operators have a mean herd size of 97 cows (median 62 cows). In contrast to the rapid growth in average herd size seen in the Wisconsin dairy sector overall in recent years, the alternative farms did not change dramatically in herd size from 1997 to 2002/2003.

Sector Divergence in Patterns of Modernization

The divergence in farm structure and strategy laid out thus far has implications for patterns of technology use and management practices on Wisconsin dairy farms. With some technologies such as housing and milking facilities, a significant fraction of Wisconsin dairy farms still milk in stanchion or tie-stall barns that were built prior to or during the 1980s. Yet, the recent changes in size structure and farm strategies have also given rise to divergence in the adoption trends of a host of technologies and management practices[6].

Modernization is frequently used in the US agricultural circles for describing the adoption of new and often more sophisticated technologies. These technologies are assumed to keep farmers cost competitive and ideally increase farm profitability. This paper utilizes the modernization concept but also broadens it to include improvements in product quality dimensions and management of environmental impacts[35]. The development of alternative practices are examples of 'reflexive modernization'[32,36,37], which as Bell[38] states is a 'modernism that reflects on where it's going, a modernism that is self-conscious and self-critical' of the benefits associated with technological advances in the predominant (or conventional) agricultural system. Reflexive consumers and producers become more concerned about issues like the environment, genetic modification and health[32,36,37,39,40].

These concerns may be a reflection of the environmental and social problems with conventional agricultural systems. Pesticides, in particular, can have detrimental effects on ecological and human health[41–44]. The degradation of soil quality caused by destructive agricultural practices may lead to increasing needs for inputs like fertilizers and irrigation[45,46]. The common practice of prophylactic treatment of antibiotics in confined livestock production is causing antibiotic resistance problems in both animals and humans[47,48]. There is a need for new approaches that capitalize on human knowledge and skills so that harm to the environment can be minimized[49].

In the context of the dairy industry, the adoption of management-intensive rotational grazing, organic farming practices and more intensive nutrient management are examples of this broader concept of modernization. Intensive rotational grazing may have sustainability benefits, such as reductions in soil erosion, fossil-fuel expenditure[50], and nitrogen volatization[51] as well as providing enhanced dimensions of soil ecological health[52,53] and better habitats for fauna. Intensive rotational grazing, especially on improved pastures, may also offer additional agronomic benefits in terms of productivity and

Table 1. Infrastructure, management and technology on Wisconsin dairy farms (% of farms).

	Dairy farms by management type				Herd size under 100 cows
	Amish (a)	Organic (b)	Grazier (c)	Confinement (d)	
Milking system					
Stall barn with buckets	96.8 bcd	3.6 ac	22.6 abd	7.0 ac	13.2
Stall barn w/pipeline	1.0 bcd	67.5 a	68.3 a	69.3 a	79.1
Flat parlor	2.1	3.6	1.8	3.7	1.6
Pit parlor	0.0 bcd	25.3 ac	5.5 abd	19.3 ac	4.9
Housing					
Tie stall stanchion	98.7 bcd	70.8 ac	88.2 abd	71.7 ac	90.2
Bedding pack housing	1.3 c	6.2 d	6.8 ad	1.0 bc	2.4
Retro freestall (existing building converted to freestall housing)	0.0 bd	18.5 acd	0.6 bd	5.9 abc	3.0
New or modern Freestall	0.0 bcd	4.6 acd	4.4 abd	21.3 abc	4.4
Management and technology					
Use of computers	0.0 b	42.7 ac	24.7 abd	41.5 ac	29.2
Keep production records	16.3 bcd	65.9 a	56.4 ad	66.5 ac	59.8
Use of TMR[1]	0.0 bcd	32.5 acd	13.7 abd	47.4 abc	26.4
rBST[2]	0.0 cd	0.0 cd	7.5 abd	25.4 abc	13.1
Balance Feed Ration	12.6 bcd	45.7 acd	55.3 abd	69.8 abc	58.9
Regularly scheduled vet services	3.1 bcd	49.4 ad	46.9 ad	75.6 abc	64.0

[1] TMR = total mixed ration (grains, minerals, vitamins and protein supplements are mixed for creating nutrient-rich animal feed).
[2] rBST = recombinant bovine growth hormone (it is used to increase milk production).

forage and soil quality[54–57]. Organic farming may also offer social and environmental benefits such as increased biodiversity, erosion control, increased soil health and reduced usage of chemicals and antibiotics[58–63].

In contrast, the unique and more traditional technology adoption patterns amongst the Amish would more accurately be attributed to religious and cultural community norms that are less likely to be examples of reflexive modernization. However, Amish farms may offer some environmental benefits. For example, the main consistent difference between Amish and the other farmer types is using horses for tillage, which may be associated with better soil quality as less soil may be lost as it is thrown up at lower levels than by using the mechanic tiller. In a comparative study with an Amish farm and a no-till farm, the Amish farm was found to have more organic matter[64]. So in summary, this paper demonstrates a more subtle account that goes beyond the common argument that links a common conception of 'modernization' in dairy to larger farmers[65,66].

Technology adoption

In Wisconsin, the adoption of parlors, freestall housing and several technologies aimed at enhancing the milk production of cows have been strongly associated with herd expansions. Those associations are evident in Table 1, but a careful examination also demonstrates strong modernization outcomes on certain types of alternative, smaller scale dairy farms. The adoption patterns on organic dairy farms are particularly striking. They utilize modern milking facilities and housing structures and have much higher adoption rates of some technologies than their herd-size distribution alone would predict in a sample of conventional farms.

The adoption of different types of milking parlors and freestall housing by farming strategy is perhaps the most powerful example where adoption of technology does not necessarily imply large and/or expanding herd sizes. About a quarter of organic operations have a pit parlor and some type of freestall housing. These adoption rates are, respectively, five times and three times the adoption rates amongst a random sample of farms that were under 100 cows (Table 1). The high adoption rate of these technologies is especially surprising given that the trend statewide has been one where parlor use has usually been very closely correlated to dairy farms undergoing major expansions in herd sizes usually to 150–200 cows[6]. In contrast, organic farmers have not increased their herd sizes dramatically, and do not express the intention of expanding significantly in the future.

Organic farmers also have adoption rates of other technologies that are higher than all but the largest confinement herds. Computer usage amongst organic farms is 13% more likely than would be predicted by a random sample of farms in the under 100 cow herd size category.

Table 2. Manure and pasture-management choices (% of farms).

	Dairy farms by management type			
	Amish (a)	**Organic (b)**	**Graziers (c)**	**Confinement (d)**
Put manure directly into a spreader and/or spread daily	79.0 bcd	16.0 acd	68.3 abd	57.2 abc
Piling manure	9.87 b	20.0 acd	10.4 b	6.7 b
Store manure in lined structures	1.2 bcd	45.3 acd	17.1 abd	33.2 abc
Is pasture your primary source of forages?	97.9 bcd	65.4 ad	68.5 ad	36.7 abc
Rotation frequency	bcd	acd	abd	
Once a day or more	11.6	46.3	25.7	
Every 2–6 days	29.1	28.8	34.1	
About once a week	29.1	10.0	40.2	
Less than once a week	30.2	15.0	0.0	

The probability that organic farmers keep individual cow production records is similar to farmers managing larger confinement herds. The use of total mixed rationing equipment amongst organic farmers is also relatively high compared to a random sample of herds under 100 cows.

At the other end of the technology adoption spectrum, the Amish utilize more traditional milking facilities than even their small size distribution would suggest. The vast majority of Amish producers have a stall barn with a bucket system and milk by hand. Thus, the Amish are utilizing older milking facilities and housing structures or setting up lower technology operations. As one might expect, the Amish adopt 'modern' technologies at rates that are roughly 25% or less than the other farming types.

MIRG farmers have adoption levels of milking structures and housing that are more typical of other moderately sized farms (with the exception of higher usage levels of bucket milking systems perhaps due to the presence of some Amish in the grazier sample). They also have a lower probability of utilizing computers than organic farmers (25% against 43%). It is possible that MIRG farmers have more basic milking structures and housing and technology use because of their lower expectations to stay in farming. As one organic dairy farmer in an on-farm interview states about graziers 'the graziers may think that I am going to retire this way, and in a few years I am going to sell the place ... graziers would put less money into it ... [They work] closer to the backbone ....'

Some technology adoption decisions are affected by the core strategy of the farm, as we see the pasture-based farmers utilizing milk productivity enhancing technologies such as rBST at much lower levels. Not surprisingly, organic dairy producers report no use of rBST, as it is a stipulation of organic certification. Growth hormones are also not allowed by the Amish in this region, partly due to the belief that they are 'not natural' as stated by an Amish elder in the Kickapoo Valley. Only one in 15 MIRG farmers report the use of the synthetic hormone, as compared to one in four confinement operations. The lower rBST adoption rates amongst the MIRG farmers are similar to what one would predict of farms under 100 cows following the common modernization argument. Similarly, balanced feed rations and total mixed rationing equipment (TMR) are used less on pasture-based farms than on confinement herds, with the Amish at the bottom end of the adoption spectrum.

Surprisingly, given the similar pasture-based focus, organic farmers use TMR at about two and a half times the rate of MIRG farmers. Organic dairy farm operations and MIRG operations look similar in their lower frequency of use of veterinarian services as compared to confinement dairy farms. While this gap may originate in the constraints organic farmers face on the use of certain types of veterinary medicine, it may also be that lower veterinary use rates are a function of better herd health due to potential benefits of pasture-based management[67,68] and longer term organic systems on herd health[69]. The small proportion of Amish that utilize scheduled veterinary services (3%) is an especially stark contrast to the vet use amongst the other management types. According to on-farm interviews, some of the Amish use a significant amount of home remedies and rely on veterinarians only as a last resort.

Manure and pasture management practice adoption

Dairy studies that focus on manure management suggest that larger farms are more likely to follow recommended practices than are smaller farms, as they are able to spread the substantial fixed costs of storage systems out over a larger operation as well as having more specialized labor[70,71]. The recommended strategy is to store in a lined structure and haul mostly in the spring and fall when tillage incorporates manure into the soil after spreading[72]. Manure is neither collected nor stored on many Wisconsin dairy farms, which could be explained, at least in part, by financial and labor constraints on small- to medium-sized operators in Wisconsin[72,73].

However, as shown in Table 2, organic dairy farmers are far less likely (16%, compared to 68% for MIRG, 79% for Amish and 57% of confinement operators) to put manure directly into a spreader than are the other types of dairy

farmers. Rather, organic farmers are much more likely to either store the manure in a lined structure (45%) or in a pile (20%), practices that are generally considered to be more environmentally beneficial. This stark difference in manure management practices between organic dairy farmers and all other management types may be due to the higher incentives organic farmers face for efficiently utilizing manure as a source of nitrogen, given certification restrictions on their use of chemical fertilizers. In contrast, the less intensive manure management practices in the other pasture-based groups are more similar to the typical farms in that herd size category.

Organic farmers are also the most likely to rotate their cows in an intensive manner and the Amish are the least likely of the pasture-based groups to rotate intensively (see Table 2). The average rotation frequency of MIRG farms overall is in between these two extremes. About one-half (46%) of organic dairy farmers rotate pasture once a day or more, as compared to only one in four (26%) of the MIRG farmers and 11% of the Amish farmers. On a national scale, the extent of pasture exposure and intensity of management may vary across organic farms as national pasture standards are not totally explicit. However, these data indicate that the majority of organic farms in Wisconsin rely on pasture to a significant extent and manage it in an intensive fashion. Almost all (98%) organic producers rely on pastures for at least part of the forage ration and about two-thirds (65%) rely on pastures for the primary source of forages. These rates are similar to the extent of pasture reliance for MIRG farms. According to the survey results, almost all Amish producers rely on pastures extensively rather than intensively, yet they indicate that pasture was their primary source of forage during the grazing months. It appears then that the Amish rely heavily on pastures that are likely to be only moderately productive.

Overall, the diversity of farm structure shapes technology adoption outcomes in the Wisconsin dairy industry, with larger confinement farms being more likely to adopt some of the modern technologies and management practices. Yet, there are also very important and distinctive dimensions of the modernization story that are evident on the smaller scale alternative dairy farms, especially on organic dairy farms. Organic farmers use a hybrid of modern milking and housing structures which are combined with a range of practices that are 'reflexive', but also clearly intensive and innovative in their management demands. Organic farm-adoption patterns seem to follow the trend in some research which finds a positive relationship between smaller farm sizes and sustainable agricultural practices[74] given their progressive adoption patterns towards management practices like manure and pasture management.

Amish farms, for the most part, stand in contrast to this modernization story as many of the technology and management practices are far less modern and intensive than on any other farm system. These extremes highlight the diversity in technology and management practices that has emerged over the past two decades in America's dairyland.

Productivity, Performance and Satisfaction

The impact and viability of these diverse types of dairy farms will depend on a multitude of factors. In this section, we compare a few critical performance indicators: herd productivity levels; farmers' self-reported satisfaction with income and quality of life; and their expectations for how long they envision themselves farming. These comparisons suggest some distinctive reasons why organic and Amish farms will continue to play an increasing role in the Wisconsin dairy industry well into the future.

Organic and MIRG farms have similar levels of milk productivity (52 versus 55 lbs per cow per day), but productivity is significantly lower on these pasture-based farms than on confinement farms. It is worth noting that large-scale confinement farms are also significantly more productive than the smaller scale confinement producers. Among the pasture-based systems, productivity levels did not vary much by grazing intensity level. Average productivity on Amish farms is around 48 lbs per cow per day which is 8% less than average production levels on organic (at 53 lbs per cow day) and 12% less than grazing farms (at 55 lbs per cow per day) and 25% less than conventional producers (at 64 lbs per day). Given that Amish producers milk by hand, these nearly comparable production levels suggest that intense labor efforts on Amish farms may explain why they manage smaller herds. The combination of fewer cows and low productivity levels mean that Amish milk production and acres operated comprise only about 1% of the total Wisconsin dairy sector even though they comprise 5–7% of the farms. Organic farms account for no more than 2% of milk production in Wisconsin currently, with MIRG farms accounting overall for less than 20% of total milk production.

Organic and Amish dairy farmers report relatively high levels of satisfaction with net farm income and overall quality of life compared to other types of dairy farms (see Table 3). Well over half of the organic farmers (57%) are satisfied or very satisfied with net farm income and 76% are satisfied or very satisfied with overall quality of life. By contrast, only 5–10% of the other non-Amish dairy farmers reported being satisfied or very satisfied with net farm income in a comparable survey. The high levels of satisfaction with income that organic farmers express likely reflect significant improvements in income over the previous 5 years that other farmers have not experienced (Fig. 3).

It should be noted that the average organic milk price received by organic dairy farms in 2003 was $19.50 per cwt ($18.20 base price), or roughly $7.00 greater (or 60% higher) than non-organic operations. Hence, the striking difference in satisfaction levels with net farm income and quality of life in the 2003–04 data may be muted in other years, such as 2005, when there was not as stark a contrast between conventional and organic prices (Fig. 3). MIRG and confinement farmers did report a more positive view on their overall quality of life with 68% of the former

Table 3. Satisfaction and future of farm life (% of farms).

	Dairy farms by management type				Large confinement (e)	Small confinement (f)
	Amish (a)	Organic (b)	Grazier (c)	Confinement (d)		
Net farm income						
Satisfied and beyond 2005	29.7 bcd	57.3 acd	5.9 ab 10.2	5.1 ab 14.5	9.8 f	4.8 e
Family quality of life						
Satisfied and beyond 2005	91.0 bcd	75.9 acd	45.9 ab 68.4	42.0 ab 58.7	35.9	43.2
Expected length of farming career						
Beyond 10 years	74.4 d	70.4 cd	27.3 b	24.1 ab	30.8	23.7
Expansion and improvement						
Very likely to make major increase in dairy herd size (more than 20%)	10.1 cd	7.4	1.9 ad	9.2 ac	23.1 f	7.1 e
Very likely to make major improvements in your milking facilities and or dairy housing facilities	8.3	9.9	5.2 d	10.2 c	20.5 f	8.4 e

Figure 3. Organic price versus conventional dairy pay price comparisons, 1989–2008. (Sources: from Organic Valley (CROPP) which indicates Organic Valley Midwest base price without butterfat or quality premiums. Conventional pay price data are from DPW Markets, Ken Bailey, Penn State Forecast.)

reporting satisfaction levels that were satisfied or very satisfied in 2005 compared to only 46% having satisfaction levels at those levels in 2002. Over half (59%) of the confinement farmers reported being highly satisfied in 2005 compared to only 42% in 2002. When asked what price they would need to remain profitable, organic farmers, on average, reported needing $16.80 per cwt, which was well below the price they were earning at the time and at any time during the past decade. Since 2004, the mean organic milk price has been well above $18.00, buffering organic farmers from the down-side price pressures that have been so challenging for other types of dairy farms.

Large confinement operations (greater than or equal to 200 cows) report somewhat higher satisfaction levels with respect to income than other dairy farm types, but they do not have levels of satisfaction comparable to those reported

by organic or Amish dairy farmers. Relatively high levels of satisfaction in larger confinement farms are also evident in other studies on dairy farm modernization[75] and quality of life[31], and appear to be explained both by higher incomes and more freedom to take time away from the farm. Because over 80% of household income comes from farming across all types of dairy farms in our sample, the strong performance of farm income on organic dairy farms indicates that they are also more likely to experience satisfactory overall family income levels compared to other farm types. From 2002 and 2005 data, we analyzed that satisfaction with income and overall quality of life did not vary consistently with grazing intensity level. Note, though, that again both organic and Amish farmers reported higher quality of life outcomes than other types of dairy farmers. If we combine the results of the two satisfaction measures in Table 3—Satisfaction with net farm income and Satisfaction with family's quality of life—we see that the majority of Amish dairy farmers have high satisfaction levels with respect to overall quality of life (91%), but the majority do not have high satisfaction levels with respect to net farm income (30%). In 2003, Amish farmers were only receiving $10.03 per cwt for their Grade B milk. The Amish farmers' high satisfaction with life and thus their survival on the farm may be a reflection of their dedication to simple living and contentment with life (1 Timothy 6:6–9)[21]. When asked what is the biggest obstacle for the Amish people, an Amish elder in the Kickapoo Valley responded by stating, 'The devil. He is very busy. In prosperity, the devil gets a lot of people. When prosperity goes too far, it is dangerous. We should make a living but not more.'

The Amish are also more likely to use non-farm self-enterprise activities (21%) against off-farm employment income (6%) to support household income. For the other types of dairy farms, off-farm rather than on-farm employment does not play as significant a role. This contrast reflects the Amish commitment to a rural lifestyle, self-reliance, insulation from the surrounding culture, and the limited employment opportunities given transportation and technology restrictions. As is well known, Amish operate a variety of farm cottage industries on their farms which include saw mills, woodwork, bakery, quilts and processing food products, all of which are used for securing additional income for the household. In addition, more than one-third (38%) of the Amish dairy farmers in our study also grow and market vegetables. Many Amish market their produce through a local produce auction and to the same organic co-operative, CROPP, which buys much of the fluid organic milk in Wisconsin.

Organic and Amish farmers are more likely than other dairy farm types to report plans to stay in farming for the indefinite future, which is consistent with their high overall satisfaction levels with quality of life. Seventy percent of organic farmers and 74% of Amish farmers expect to stay in farming for the indefinite future (i.e., beyond 10 years), compared to 27 and 24% of MIRG and confinement farmers, respectively. The intentions of expanding and improving are modest amongst all the farm strategies especially amongst the pasture-based farmers, with MIRG farmers being even less likely to consider those changes given their lower reported levels of intention to remain in farming for many years. Confinement operations are the most likely to expect future expansion with one out of four considering either expanding their herd size significantly or improving their milking or housing facilities. Grazing intensity also did not affect the farmer's intention to stay in farming nor the farmer's intentions to expand or improve farm infrastructure. One distinguishing aspect of the MIRG strategy is that it may provide an easier transition to other farming or career endeavors given the lower levels of sunk investments involved compared to the infrastructure necessary for implementing confinement systems[76]. It is also important to emphasize that MIRG farmers are in a better position to switch to organic, given their pasture-based focus, though some may decide that the knowledge and investment costs associated with transitioning to organic are too high. According to the performance data analyzed here, especially the organic and Amish dairy farms should persist and grow in the years to come.

Conclusions

Structural change and increasing diversity of management strategies in the Wisconsin dairy farm sector are strongly intertwined. In the past two decades alternative pasture-based farms have emerged which are typically smaller in scale and less capital-intensive, in contrast to the more commonly documented theme of industrialization with the proliferation and growth of large-scale confinement farms. This paper demonstrates that the divergence in management strategies has implications for structure, technology and management adoption patterns as well as farmer satisfaction levels. The emergence of different farm types suggests that there are multiple ways by which farmers choose to live out economic, social/spiritual and ecological values.

The organic farm strategy seems to be especially vibrant, based on farmer satisfaction levels with overall quality of life and income, which is also reflected in their high expectations for their future in farming. Organic farmers are also progressive in their adoption of modern technologies, especially considering their moderate size. Amish dairy producers have a solid and growing presence on the farm landscape despite their low production levels, small herd sizes and modest adoption of moderate technologies, which perhaps is made possible by their relatively low expectations for income and consumption and their strong preference for a rural, culturally insulated lifestyle. The MIRG farm strategy overall continues to be a low input and perhaps also a low-cost strategy in the conventionally priced market. Further research is needed for comparing rigorous farm-based economic performance indicators, especially various measures of profitability, and to explore factors (farming strategy, technology use, number of rotations, acreage/per cow) that may contribute to higher

levels of economic performance amongst these alternative and confinement farm strategies in Wisconsin, as well as other states.

At the environmental level, we see that organic dairy farmers appear to be quite proactive in terms of adoption of management practices that may have positive impacts, such as progressive manure management practices and intensive rotational grazing practices. The Amish and MIRG farmers offer some of these same benefits, given their pasture-management focus, but their management intensity with respect to these practices is considerably lower than that in the organic farms. However, more research is needed to make comprehensive environmental sustainability comparisons between these groups of dairy farmers.

These farm systems are worth considering at a societal level as well, as the role of personal values, environmental stewardship and other non-pecuniary dimensions may be central to the decisions made by dairy farm families. This is especially evident with the proliferation of Amish farms. For the Amish, their motivations and purpose in farming are not strongly tied to income levels or other standard economic measures. As an entry in an Amish newsletter states, '*Farming is not a top paying job .... Isn't farming still the most important and best for the family?*'[77]. Many of these Amish individuals are quite committed to continue farming despite low levels of satisfaction with farm income. The niche of dairy farming at a small scale with a low cost/minimal technology approach helps preserve the Amish way of life as it involves the family on a daily basis throughout the year.

Also, clearly, organic farming is often viewed as a way to live out values on health and the environment, especially amongst some of the originators of the movement. The MIRG system is more flexible for farmers who want the option to use non-organic practices. This system also does not entail the administrative work involved with organic marketing. In this way, diversity in dairy farm systems provides multiple avenues for farmers to match the management system to varying landscape and biophysical conditions and meet their own personal goals.

This paper indicates that alternative dairy farming systems will likely become more prevalent on the agricultural landscape of Wisconsin. Both organic and Amish farm numbers are growing rapidly, and the proportion of MIRG farms seems to be holding steady. It also provides one of the first statistically representative comparisons of the diverse structure, behavior and performance of alternative dairy farm strategies which are growing in prevalence in traditional dairy states like Wisconsin. Much remains to be learned about farmers' choices with respect to size and farm strategy, their viability in terms of profitability, as well as their satisfaction with quality of life given their choices. With the Amish, we might see a different picture of farm structure and performance, if we were to study more liberal Amish settlements in Wisconsin and other states. The extent of overlap between the Amish and the adoption of organic and management-intensive grazing practices is also an important research topic. In sum, future systematic comparisons on economic, environmental and social dimensions will likely be useful for informing farmers regarding their choice of farming systems and for guiding other public and private decision makers as they work with farmers and communities to achieve desired outcomes and for mitigating undesirable ones.

Acknowledgements. We are grateful to the producers who provided invaluable information on the state's agricultural sector and the student assistants who spent many hours assisting in data entry and cleaning.

References

1 Blayney, D. 2002. The changing landscape of U.S. milk production. Statistical Bulletin SB-978. US Department of Agriculture. Economic Research Services, Washington, DC.
2 Gilbert, J. and Wher, K. 2003. Dairy industrialization in the first place: urbanization, immigration, and political economy in Los Angeles County, 1920–1970. Rural Sociology 68(4):467–490.
3 Geisler, C. and Lyson, T. 1991. The cumulative impact of dairy industry restructuring. BioScience 41(8):560–567.
4 Cross, J.A. 2006. Restructuring America's dairy farms. Geographical Review 96(1):1–23.
5 Cross, J.A. 2007. The expanding role of the Amish in America's dairy industry. Focus on Geography 50(3):7–16.
6 Jackson-Smith, D. and Barham, B. 2000. Dynamics of dairy industry restructuring in Wisconsin. In H. Schwarzweller and A. Davidson (eds). Dairy Industry Restructuring: Research in Rural Sociology and Development. Elsevier Science, NY. p. 115–141.
7 Albrecht, D. 1997. The changing structure of US agriculture: dualism out, industrialism in. Rural Sociology 62(4):474–490.
8 Jackson-Smith, D.B. and Buttel, F. 1998. Explaining the uneven penetration of industrialization in the U.S. dairy sector. International Journal of Sociology of Agriculture and Food 7:113–150.
9 Cross, J.A. 2004. Amish settlements in Wisconsin. Wisconsin Geographer 20:2–9.
10 USDA National Agriculture Statistics Services (NASS). 2006. Wisconsin dairy operations by size and quick national statistics [Online]. Available at Web site http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/dyopbysizegroup.pdf/ and http://www.nass.usda.gov/QuickStats/PullData_US.jsp/ (verified 4 September 2007).
11 Guthey, G.T., Gwin, L., and Fairfax, S. 2003. Creative preservation in California's dairy industry. Geographical Review 93(2):171–192.
12 Welsh, R. and Lyson, T. 1997. Farm structure, market structure and agricultural sustainability goals: the case of New York state dairying. American Journal of Alternative Agriculture 12(1):14–18.
13 Nott, S.B. 2003. Evolution of dairy grazing in the 1990s. Department of Agricultural Economics, Michigan State University, East Lansing, MI.
14 Taylor, J. and Foltz, J. 2006. Grazing in the dairy state: the significance of pasture use in the Wisconsin dairy industry 1993–2003. PATS/CIAS Special Report. Center for Integrated

Agricultural Systems, University of Wisconsin-Madison, Madison, WI.
15 Dartt, B., Lloyd, J., Radke, R., Black, J., and Kaneene, J. 1999. A comparison of profitability and economic efficiencies between management-intensive grazing and conventionally managed dairies in Michigan. Journal of Dairy Science 82(11):2412–2420.
16 Parsons, R.L., Luloff, A., and Hanson, G. 2004. Can we identify key characteristics associated with grazing-management dairy systems from survey data? Journal of Dairy Science 87:2748–2760.
17 Dalton, T.J., Bragga, L.A., Kersbergen, R., Parsons, R., Rogers, G., Kauppilad, D., and Wange, Q. 2005. Cost and returns to organic dairy farming in Maine and Vermont for 2004. Department of Resource Economics and Policy Staff Paper, Department of Resource Economics, University of Maine, Bangor, ME.
18 Barham, B., Brock, C., and Foltz, J. 2006. Organic dairy farms in Wisconsin: prosperous, modern, and expansive. PATS Research Report 16. Program on Agricultural Technology Studies, University of Wisconsin—Madison, Madison, WI.
19 United States Department of Agriculture-Economic Research Service. 2005. Organic production data set [Online]. Available at Web site http://www.ers.usda.gov/Data/Organic/ (verified 1 November 2007).
20 Luthy, D. 2003. Amish Settlements Across America. Pathway Publishers, La Grange, IN.
21 Hostetler, J. 1993. Amish Society. 4th ed. John Hopkins Press, Baltimore, MD.
22 Cross, J.A. 2004. Expansion of Amish dairy farming in Wisconsin. Journal of Cultural Geography 21(2):77–101.
23 Foltz, J. and Lang, G. 2005. The adoption and impact of management intensive rotational grazing (MIRG) on Connecticut dairy farms. Renewable Agriculture and Food Systems 20(4):261–266.
24 Dillman, D.A. 1978. Mail and Telephone Surveys: The Total Design Method. John Wiley and Sons, NY.
25 USDA United States Department of Agriculture. 1987. US Census of Agriculture.
26 Hinrichs, C. and Welsh, R. 2003. The effects of the industrialization of US livestock agriculture on promoting sustainable production practices. Agriculture and Human Values 20(2):125–141.
27 Lyson, T.A. and Gillespie, G. 1995. Producing more milk on fewer farms: neoclassical and neostructural explanations of changes in dairy farming. Rural Sociology 60(3):493–504.
28 Hassanein, N. 1999. Changing the Way America Farms: Knowledge and Community in the Sustainable Agriculture Movement. University of Nebraska Press, Lincoln, NE.
29 Fales, S.L., McMurry, S.A., and McSweeny, W.T. 1992. The role of pasture in northeastern dairy farming: historical perspectives, trends, and research imperatives for the future. In T. Sims (ed.). Agricultural Research in the Northeastern United States: Critical Review and Future Perspectives. American Society of Agronomy, Madison, WI. p. 111–132.
30 Voisin, A. 1959. Grass Productivity. Philosophical Library Press, NY.
31 Lloyd, S., Bell, M., and Stevenson, G.W. 2007. Milking more than profit: life satisfaction on Wisconsin dairy farms. Center for Integrated Agricultural Systems, University of Wisconsin-Madison, Madison, WI.
32 DuPuis, M. 2000. Not in my body: BGH and the rise of organic milk. Agriculture and Human Values 17(3):285–295.
33 Guptill, A. 2006. Organic feed and organic dairies in Upstate New York. Paper presented to Place, Taste, and Sustenance: The Social Spaces of Food and Agriculture 7–11 June, Boston University, Boston, MA.
34 Kraybill, D. 2001. The Riddle of Amish Culture. Center for American Places, Santa Fe, Mexico.
35 Holmes, B., Kammel, D., and Palmer, R. 2005. Transitioning in steps-cost of modernization. University of Wisconsin Biological Systems and Engineering, Madison, WI.
36 Kaltoft, P. 2001. Organic farming in late modernity: at the frontier of modernity or opposing modernity? Sociologia Ruralis 41(1):146–158.
37 Stock, P. 2007. 'Good farmers' as reflexive producers: an examination of family organic farmers in the US Midwest. Sociologia Ruralis 47(2):83–102.
38 Bell, M. 2004. Farming for Us All: Practical Agriculture and the Cultivation of Sustainability. Pennsylvania State University, University Park, PA.
39 Beck, U. 1995. The conflict of two modernities. In Ecological Enlightenment: Essays on the Politics of the Risk Society. Humanities Press International, Atlantic Highlands, NJ.
40 Lockie, S., Lyons, K., Lawrence, G., and Mummery, K. 2002. Eating 'green': motivations behind organic food consumption in Australia. Sociologia Ruralis 42(1):23–40.
41 Spiewak, R. 2001. Pesticides as a cause of occupational skin diseases in farmers. Annals of Agricultural and Environmental Medicine 8(1):1–5.
42 Porter, P., Jaeger, J., and Carlson, I. 1999. Endocrine, immune, and behavorial effects of aldicarb (carbamate), atrazine (triazine) and nitrate (fertilizer) mixtures at groundwater concentrations. Toxicology and Industrial Health 15(1–2): 133–150.
43 Pereira, W. and Hostettler, F. 1993. Nonpoint source contamination of the Mississippi River and its tributaries by herbicides. Environmental Science and Technology 27(8):1542–1552.
44 Schreinemachers, D. 2000. Cancer mortality in four northern wheat-producing states. Environmental Health Perspectives 108(9):873–881.
45 Cassman, K. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proceedings of the National Academy of Sciences of the United States of America 96(11):5952–5959.
46 Fox, J., Gulledge, J., Engelhaupt, E., Burow, M., and McLachlan, J. 2007. Pesticides reduce symbiotic efficiency of nitrogen-fixing rhizobia and host plants. Proceedings of the National Academy of Sciences of the United States of America 104(24):10282–10287.
47 Smith, K.E., Besser, J., Hedberg, C., Leano, F., Bender, J., Wicklund, J., Johnson, B., Moore, K., and Osterholm, M. 1999. Quinolone-resistant *Campylobacter jejuni* infections in Minnesota, 1992–1998. New England Journal of Medicine 340(20):1525–1532.
48 Gorback, S. 2001. Antimicrobial use in animal feed—time to stop. New England Journal of Medicine 345:1202–1203.
49 Pretty, J. 2008. Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1491):447–465.
50 Rayburn, E.B. 1993. Potential ecological and environmental effects of pasture and rBGH Technology. In W.C. Liebhardt (ed.). The Dairy Debate: Consequences of Bovine Growth

Hormone and Rotational Grazing Technologies. University of California Sustainable Agriculture Research and Education Program. Davis, CA. p. 247–276.

51 Soder, K.J. and Rotz, C.A. 2001. Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. Journal of Dairy Science 84(11):2560–2572.

52 Johnson, N. and Pfleger, F.L. 1992. Vesicular mycorrhizae and cultural stresses. In G.J. Bethlenfalvay and R.G. Linderman (eds). Mycorrhizae in Sustainable Agriculture. American Society of Agronomy, Madison, WI. p. 71–101.

53 Rabatin, S. and Stinner, B. 1989. The significance of vesicular–arbuscular mycorrhizal fungal–soil macroinvertebrate interactions in agrosecosystems. Agriculture, Ecosystems and Environment 27:195–204.

54 Martz, F. 1999. Nutrient content, dry matter yield, and species composition of cool-season pasture with management-intensive grazing. Journal of Dairy Science 82:1538–1544.

55 Henning, J., Lacefield, G.D., Rasnake, M., Burris, R., Johns, J., Johnson, K., and Turner, L. 2000. Rotational Grazing. Cooperative Extension Service, University College of Agriculture, University of Kentucky Cooperative Extension Service, Turner, Frankfurt.

56 Pratt, A.D. and Davis, R.R. 1962. Rotational grazing and green chopping compared. Ohio Farm and Home Research 47(3):38–39.

57 Kuusela, E. and Khalili, H. 2002. Effect of grazing method and herbage allowance on the grazing efficiency of milk production in organic farming. Animal Feed Science and Technology 98(1):87–101.

58 Haas, G., Wetterich, F., and Köpke, U. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agriculture, Ecosystems and Environment 83:43–53.

59 Pacini, C., Wossink, A., Giesen, G., Vazzana, C., and Huirne, R. 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. Agriculture, Ecosystems and Environment 95(1):273–288.

60 Rigby, D. and Caceres, D. 2001. Organic farming and the sustainability of agricultural systems. Agricultural Systems 68(1):21–40.

61 Cederberg, C. and Mattsson, B. 2000. Life cycle assessment of milk production—a comparison of conventional and organic farming. Journal of Cleaner Production 8(1):49–60.

62 Smolik, J.D., Dobbs, T.L., and Rickerl, D.H. 1995. The relative sustainability of alternative, conventional, and reduced-till farming systems. American Journal of Alternative Agriculture 10(1):25–35.

63 de Boer, I.J.M. 2003. Environmental impact assessment of conventional and organic milk production. Livestock Production Science 80:69–77.

64 Jackson, M. 1988. Amish agriculture and no-till: the hazards of applying the USLE to unusual farms. Journal of Soil and Water Conservation 43(6):483–486.

65 Barham, B. 2000. The adoption of rBST on Wisconsin dairy farms. AgBioForum 2(2–3):181–187.

66 Brannstorm, A. 2006. Wisconsin dairy modernization survey [Online]. Available at Web site http://cdp.wisc.edu/pdf/Dairy%20Modernization%20Survey%202006.pdf (verified 1 October 2007).

67 Goldberg, J., Wildman, E., Pankey, J., Kunkel, J., Howard, D., and Murphy, B. 1992. The influence of intensively managed rotational grazing, traditional continuous grazing, and confinement housing on bulk tank milk quality and udder health. Journal of Dairy Science 75:96–104.

68 McCue, J. 2004. Management of bacterial burden in cattle by TiO_2 from grazing. Journal of Dairy Science 87:1579.

69 Bennedsgaard, T., Thamsborgb, S., Vaarstc, M., and Enevoldsend, C. 2003. Eleven years of organic dairy production in Denmark: herd health and production related to time of conversion and compared to conventional production. Livestock Production Science 80(1):121–131.

70 Burton, M., Rigby, D., and Young, T. 1999. Analysis of the determinants of adoption of organic horticultural techniques in the UK. Journal of Agricultural Economics 50(1):47–63.

71 Fulhage, C.D. 1997. Manure management considerations for expanding dairy herds. Journal of Dairy Science 80(8):1872–1879.

72 Turnquist, A., Foltz, J., and Roth, C. 2006. Manure management on Wisconsin farms. PATS Research Reports. 15. Program on Agricultural Technology Studies (PATS) Research Report, Madison, WI.

73 Powell, M., McCrory, D.F., Jackson-Smith, D.B., and Saam, H. 2005. Manure collection and distribution on Wisconsin Dairy Farms. Journal of Environmental Quality 34:2036–2044.

74 Tavernier, E.M. and Tolomeo, V. 2004. An empirical analysis of producer perceptions of traceability in organic agriculture. Renewable Agriculture and Food Systems 19(2):110–117.

75 Bewley, J., Palmer, R.W., and Jackson-Smith, D.B. 2001. An overview of experiences of Wisconsin dairy farmers who modernized their operations. Journal of Dairy Science 84(3):717–729.

76 Barham, B., Chavas, J., and Klemme, R. 1994. Low capital dairy strategies in Wisconsin: lessons from a new approach to measuring profitability. Staff Working Paper. 381. Department of Agricultural Economics, University of Wisconsin, Madison, WI.

77 Anonymous. 2006. Schneeflocken. Plain Connections (Amish Newsletter) 5(2):11.

Renewable Agriculture and Food Systems: 24(1); 38–47 doi:10.1017/S1742170508002391

Farmers and nature conservation: What is known about attitudes, context factors and actions affecting conservation?

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Accepted 13 August 2008; First published online 10 December 2008 **Research Paper**

Abstract

Farmers' attitudes towards viability of specific conservation practices or actions strongly impact their decisions on adoption and change. This review of 'attitude' information reveals a wide range of perceptions about what conservation means and what the impacts of adoption will mean in economic and environmental terms. Farmers operate in a tight financial situation, and in parts of the world they are highly dependent on government subsidies, and cannot afford to risk losing that support. Use of conservation practices is most effective when these are understood in the context of the individual farm, and decisions are rooted in land and resource stewardship and long-term concerns about health of the farm and the soil. The attitudes of farmers entering agri-environmental schemes decide the quality of the result. A model is developed to show how attitudes of the farmer, the farming context and agri-environmental schemes interact and thus influence how the farming community affects nature and biodiversity. As new agri-environmental schemes are planned, agricultural development specialists need to recognize the complexity of farmer attitudes, the importance of location and individual farmer circumstances, and the multiple factors that influence decisions. We provide these insights and the model to conservation biologists conducting research in farming areas, decision makers who develop future agri-environmental schemes, educators training tomorrow's extension officers and nature conservationists, and researchers dealing with nature conservation issues through a combination of scientific disciplines.

Key words: attitude, biodiversity, stewardship, agri-environmental scheme

Introduction

Agricultural production methods have to be sustainable in economic, ecological, and social terms, in order to provide food for the growing global population. However, agricultural intensification and specialization have resulted in declining biodiversity and other environmental problems in agro-ecosystems[1–3]. Society has created nature conservation and environmental programs to counter these negative trends, e.g. agri-environmental schemes within the European Union (EU); these programs compensate farmers for the production of common goods and services but also for adopting environmentally friendly production strategies. Environmental programs in farmland are by necessity mediated through farmers, whose decisions on land management are affected by the programs and schemes but also other factors ranging from municipality regulations to general norms in the society. It is often uncertain how farmers will react to specific incentive strategies, but the choice is dependent in large parts on the farmers' attitudes and norms.

Siebert et al.[4] describe the integration of agriculture and biodiversity conservation as becoming a truism in the EU.

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Unfortunately, the evaluations of the different schemes are few, and most existing evaluations are neither published in peer-reviewed journals nor analyzed with proper statistics[5–7]. Further, the evaluations are hard to perform because schemes often have multiple goals ranging from purely ecological objectives to public enjoyment[8]. A major problem in the design of schemes and the supporting research is that farmers' perceptions and knowledge of nature often are neglected. According to a search in ISI Web of Knowledge using the key words nature conservation and attitudes, only 4% of the papers dealing with nature conservation issues also mentioned farmers' attitudes.

Knop et al.[7] conclude that to create efficient agri-environmental schemes it is necessary to build in possibilities for regional and local adaptations of the prescribed management. Bengtsson et al.[9] argue that large-scale schemes such as those imposed by the EU need to be more farm and landscape specific. Farming, nature conservation and biodiversity are not static and will change, and thus advice and schemes have to be adaptable to new circumstances. When working on a socio-economic unit such as a farm, which is embedded within a larger landscape and economic/social environment, agri-environmental schemes should consider a number of ecological scales and include different disciplines, such as natural and social sciences and economics[10]. Biodiversity is positively associated with high landscape heterogeneity[11,12]. Firbank[12] argues that more heterogeneity in the landscape would be one result of less rigid schemes with more reliance on the farmer to operate in a sound way. However, some organisms often depend on landscape factors or parameters not included in the scheme[13].

Development of schemes has increasingly been done in cooperation among stakeholders, and this has led to mutual benefits[14]. Also important in the development of schemes is cooperation with different scientific disciplines to extract baseline information about the farmers' willingness to engage in conservation actions, which is affected by many parameters[10]. To successfully implement the schemes, support is needed from a broad range of people from governments to businesses, and from farmers to local residents. Financial support is often crucial, but advice, feedback, and recommendations of measures that farmers feel positive about also increase the likelihood of the scheme to be effective[6].

The starting point of this paper is literature on farmers' attitudes to nature conservation, and from the literature a farming context description was done. We have included farming business, farming policy, nature around the farm, extension, agri-environmental schemes, and other farmers as parts of the context. There is a need to know what the farmers see as main problems in the current policy, learn what makes them interested in nature, and determine what social and political parameters are effective incentives and disincentives in regulations and schemes for combining farming and conservation. How is the context affecting farmers' attitudes and behavior, and thus their influence on nature and nature conservation? Do subsidies or enrollment in agri-environmental schemes increase farmers' awareness of environmental issues?

The discussion in this paper focuses on how agri-environmental schemes, as part of the incentive structure for change and action created by society, affect farmers' intent to implement actions in nature conservation issues and the reasons behind the farmers' decisions to join agri-environmental schemes. Our goal is to provide an overview and critical examination of the current knowledge about farmers' perceptions of nature conservation and other factors influencing their willingness to perform nature conservation actions. Based on the literature, we developed a model (see Fig. 1) to show how relevant parameters influence the farmers and their effect on nature. Our state of departure is a farmer managing the farm according to a certain management regime that has a certain influence on biodiversity. We want to explore and show what factors are important and how these factors influence the management of the farm and especially so when another actor, for example, a governmental agency, takes action to change the management of the farm.

We provide these insights and the model for conservation biologists conducting research in farming regions, decision makers who develop future agri-environmental schemes, educators training tomorrow's extension officers and nature conservationists, and researchers dealing with nature conservation issues through a combination of scientific disciplines.

Methods

We confined our review on attitudes to literature published in scientific journals. There is a broader information base available in reports (for example Toogood et al.[15]) and working papers, but in order to make this selection of studies transparent and standardized, we chose to only use easily accessible and peer-reviewed resources. The literature was collected until spring 2005 through databases available at Webspirs and ISI Web of Knowledge. The key words used were attitudes, perception, feelings, farmers, nature and nature conservation. We also followed current literature in the field, searched the reference lists for relevant articles, and added a few more recent publications. Our review includes studies from Europe, North America and Australia/New Zealand. The review provides a timely snapshot of what is known about farmers and nature conservation actions in these regions. Fishbein and Ajzen[16] published the first paper to link attitudes and behavior (theory of reasoned action, TRA) and since then many papers have been published about attitude theory; we are aware of this literature, but do not discuss that further in this paper. We acknowledge the discussion and critique in Burton[17] and literature therein about the over-emphasis on attitudes as the main factor in the choice of actions and behavior.

Description of Farmers and their Context

In this section, we summarize the literature about how farmers are described and how farmers perceive their political, economic, and natural context. How the context is perceived is personal, and thus two farmers will experience the same situation differently.

Farmers are often characterized as having ties to the land that give them deep awareness of natural cycles, appreciation for natural beauty and a sense of stewardship, but at the same time farmers are characterized as primarily utilitarian, causing misuse of the land[18]. Thus, farmers may both care for and pollute the land simultaneously[19,20]. Farmers in the USA claim that they are good stewards and 82% describe themselves as sustainable managers of land resources[21], whereas in another study 90% of the farmers surveyed felt close to the earth[22]. Cultivating fields and managing the same land over generations give farmers a unique local knowledge and thus a good understanding of how to care for and conserve land for future generations[23].

McGregor et al.[24] showed that UK farmers claim that coping with new legislation is as stressful as coping with the weather. 'Over-regulation' of farming is seen as a major threat for recruitment of new farmers in some areas in Germany[23] and in the USA[22]. Personal benefits of farming include independence, and being close to nature because of the continuous opportunity to be outdoors[18,25]. In a study in Michigan, what farmers liked most with farming was independence but what they would miss the most if they left farming was their association with nature[18]. Farmers in US states of California and Colorado shared a love for the land and took pride in their work; camaraderie with other farmers was also important to them[22,26]. Farmers' discussions with other farmers, as well as with advisors and non-farm neighbors, are an important part of the rural community in the Netherlands[27]. To be acknowledged as a good farmer in the farming community in the UK, the appearance of the farm is important: straight planted crops, tidy ditches and managed hedges[28].

There is a fear among farmers of losing control over the land, and as a result of this fear 56% of US farmers would not allow a biological survey of their land to avoid the risk of having their land regulated[29]. Likewise, there is concern about the potential for official designation of endangered species on their land that may limit decisions in management. 'Farmers (in the UK) knew that their farming practices worked with nature and logically that was why wildlife had flourished'[30] and these farmers also said if they had done anything wrong and destroyed habitat there would be nothing to preserve. They concluded that they must have been practicing conservation. Participation in conservation programs in the UK led in many cases to increased awareness of wildlife species[31]. In cases where biologists/conservationists in the UK had taken time to show and name species made the farmer proud and more willing to take conservation actions because he or she knew what was being protected[31].

In the UK, there was mistrust by farmers toward experts from the commercial input and processing sectors[28]. In contrast, Dutch conventional farmers preferred advice from suppliers or the bank over governmental representatives[25]. Clark and Murdoch[32] showed that advice based only on science would not appear 'correct' to all farmers. The advice from experts was not seen as flexible enough, and farmers saw the lack of local and time-specific understandings of nature in the generalized recommendations.

Van der Meulen et al.[27] showed that the Dutch farmer's first impression of the conservation scheme, and more importantly the first impression of the person presenting the scheme over the phone, affected whether the farmer would join or not. For example, high levels of adoption of woody conservation stream protection plantings were found in one county in Nebraska, where the extension educator enthused about these practices, compared to neighboring counties where there was less official interest[33]. To entice farmers to apply conservation practices, these actions must be put into the larger context of the goals of the farm, both in the short and long term. Goals have to be realistic, or no one will move them seriously into actions. People working with the administration of programs have to be competent in the subject as well as in communication with clients, and committed to the purpose and results of programs[34].

Entering a conservation scheme and becoming aware of conservation is not the same thing[30,35]. The attitudes of farmers entering schemes decide the quality of the result[35]. A positive change in attitude will give greater conservation success and more conservation goods per unit of input money invested[36].

Farmer Concepts of Stewardship and Conservation

'The love of the land'[22,26] is one way to express stewardship. Here, we explore the term stewardship in the 'attitude' literature and see how it is used and described. If there is a defined stewardship feeling would it be possible to create agri-environmental schemes that support and enrich this stewardship and create successful schemes to be used by proud and still independent farmers?

'Landscape is not primarily to be conserved or preserved but to be cultivated and shaped' according to Finnish farmers[37]. The cultivation of the landscape, however, has to be done in harmony with nature without exploiting the land. Farming can be an act of stewardship. In a study from the UK[30] a farmer stated that farming depends on 'what the land would let you do'. It requires flexible management of the land depending on weather, local soils and fluctuating and unpredictable precipitation. Beedell and Rehman[38] stated that UK farmers feel they have a moral obligation to take care of the countryside, and US respondents in Duram's[26] study said that they farmed because it 'is a challenge' and 'for land stewardship'. Fairweather and Campbell[39] found that most New Zealand farmers

responded positively to the statement, 'rather than controlling nature, we need to learn to coexist with the natural environment'.

Farmers in the US Midwest were more interested in joining conservation programs that gave tidy managed habitats than programs creating untidy habitats without management such as natural growth in forests or riparian buffers[40]. An aesthetically pleasing, i.e. tidy, landscape conveys the message, to other farmers, that the manager of this land is a good steward. However, biologists might differ in their reaction to these well defined and managed 'wildlife habitats', considering them more likely an area devoid of natural variation and niches[40].

Professed sympathy towards nature conservation in the UK is argued to be overestimated[41], as the attitudes and statements expressed in many surveys are not related to real actions or management. The gap between attitude and action was shown by Wicker[42] in many social groups. There is also a great difference among stakeholders regarding the meaning of nature conservation. Carr and Tait[41] describe how farmers see themselves as conservationists, but conservationists do not agree. Farmers in southwest England described with pride how they tried to maintain landscape features such as hedges, and how they never deliberately damaged nature[31]. However, it was uncommon to find active work with nature conservation on the farm, and few farmers had ever taken conservation advice.

Stewardship feeling does not always lead to management changes. Economic matters, for instance[43], might stop the stewardship from being realized. An opinion, attitude, or perception does not have any effect until behaviors and actions change according to these factors. Vanclay[44] and Millar and Curtis[43] showed that farmers in Australia were concerned about conservation but they also reported that other factors, in this case economics, challenged the conservation concern.

In a study by McCann et al.[45], organic and conventional farmers in Michigan varied in their adoption of conservation practices, but they shared a common concern for the environmental impact of agriculture. For organic farmers, this environmental concern was manifested in adoption of sustainable practices, but for the conventional farmers the same concern did not cause behavioral change. However, in the Netherlands the common concern among conventional and organic farmers was in economic matters, but they differed greatly in their view of nature[25]. For conventional farmers, nature meant economic values and they stated, 'we have to control nature'. To the organic farmers, nature meant a normative principle and farmers should 'go with the flow' of nature[25]. Similar results were found in Norway[46].

Pyrovetsi and Daoutopoulus[47] found that farmers in a wetland area in Greece did not know or care about the environmental impacts of modern agriculture. Farmers were often concerned about general environmental issues on a community level but usually did not consider their farming practices as part of the problem[37,44].

Stewardship and conservation are terms that mean different things to different people. Carr and Tait[41] showed that farmers claim that they conserve the agricultural landscape and farming, while biological conservationists did not see that as conservation. Conservation for the latter was, instead, the species and habitats in each agricultural landscape. The same kind of reasoning can be done with stewardship. In the farmer's community to be a good steward of the land is in great contrast to the conservationists' definition of being a good steward. Ryan et al.[40] showed that farmers wanted tidy habitats, whereas conservationists wanted untidy or diverse habitats. Thus dependent on the observer, the habitat is an example of good or bad stewardship if it is untidy. The clashes of opinions between farmers and conservationists are a key obstacle for sound nature conservation in the agricultural landscape.

Factors Affecting Conservation Action Decisions

Economics

As with any individual or company, economics of farming is important. But is this the only driver for farmers? Subsidies through agri-environmental schemes may be enough to create positive effects during the scheme period, but we need to examine if they serve as a stimulus to do new things and change perceptions about other questions, and thus continue to have positive effects beyond the period of the scheme and subsidies.

'If it was just a matter of economics we would not be here', said an English farmer as reported by Harrison et al.[30]. Farmers' decisions are made under great external pressure from the market, national laws, regulations and subsidy programs. In a social climate where society demands cheaper food, and at the same time more environmentally friendly production practices, it is even harder for farmers to make management decisions. One incentive to farm in the UK was income, but at least as important was maintaining a nice place to live, being close to the land and nature, and independence[23,27,48]. The independence can be a threat as well, as many farmers in Greece felt trapped in farming, especially since they could not see how to make the farm more profitable[47].

The economic pressures on the farm may work against the application of conservation actions[45]. Farmers perceive that it is possible to earn money producing high yields with one or two well-adapted crops, while it is harder to increase profitability by enhancing biodiversity through a broader mix of crop species, given current economics and price support structures. To make the farm business profitable or at least not an economic drain puts agricultural production before conservation[49]. According to Carr and Tait[41], profit motives were stronger than environmental motives, even though farmers in the UK were aware of environmental problems. In the USA and UK the use of chemicals in

farming was greater with higher farm income, but with increased farm income also came increased usage of alternative practices and enrollment in more conservation programs[50,51]. Funding through federal programs in the USA was the trigger to start conservation efforts but it did not change the farmers' conservation attitudes. If the farmers' attitudes toward conservation had been negative, then funding had minimal and short-term impacts on their actions. However, funding was claimed to be good because it introduced farmers to new ways of doing things and to new people, to learning about what nature could do to solve a production dilemma, and learning how to live with social pressure after using less conventional management[52]. Ryan et al.[40] showed that subsidies alone were neither enough to create a willingness to join conservation programs in the USA, nor did they create a long-term and useful conservation ethic. Another problem in farming in the developed world is the heavy dependence on agricultural subsidies. Finnish farmers were annoyed that 'desk-work' was greater rewarded than 'real work', their physical activity with visible results[37].

The literature shows that farmers might be aware of environmental problems but they do not see their farming operation as a part of the problem, and thus there is no need to change anything. Other farmers might see the environmental problem and see their operation as part of the problem, but the economic situation on the farm does not permit conservation actions to be taken. Another prerequisite to join or to not join a scheme is the awareness that production and management methods might be both a cause of a decrease and an increase in farmland biodiversity[14]. Often farms with high income try to maximize profit and efficiency in all parts of the farm business, and that might lead to situations where the actions seem to contradict each other, e.g. pesticides[50,51]. The farmers need to feel supported not only with money but also with advice and engagement. Furthermore, it is important that farmers do not feel trapped in a rigid scheme, but still feel that their knowledge about production and nature is considered as an important input in the development and the realization of nature conservation in farmland.

Being a farmer is not simply a profession but a way of life and thus money is not all that matters; quality of life and independence are important. However, the fact that a larger and larger proportion of farm families earn their main income outside the farm might be the beginning of a disconnection of the tight bonds between the farmer and the land. An example is that working off farm and doing farming in spare time will lead to a great need to be fast, and a higher risk of doing the management actions when there is time, rather than doing specific operations when it is optimal to perform the actions.

Farm demographics

To better understand the impact of demographics on decisions, it is useful to examine such factors as farm size, farmer age, farm history and plans for the future. Farmers on small-scale farms in the USA express more concern toward environmental issues and incorporate more conservation strategies than farmers on industrial-scale farms[53,54]. The farmer population in the USA has changed during the past 50 years from a relatively homogeneous group of small- and medium-sized diverse family farms to today's specialized, large-scale units[55].

Traore[56] found that neither farm size nor plans for heirs to continue farming were correlated with adoption of conservation techniques in Canada. In contrast, Featherstone and Goodwin[57] found that larger farms and farmers in the USA with long-term plans for heirs to continue farming were more likely to invest in conservation measures than smaller farms. These conflicting results suggest that there are no simple answers to the question of how farm size and conservation are related.

Several studies claim that older farmers are less willing to use land-use planning and/or change farm management practices[58–60]. Other studies show that younger and more educated farmers tend to be more willing to adopt new technologies and join conservation schemes[61,62]. Farmers living on an old family farm seemed to have developed greater sympathy with the land and also appeared more interested in conservation-oriented farming, compared to relative newcomers to farming[63]. Ownership of a farm creates emotional links and willingness to honor and maintain the status of the land[64].

Farmers with successors seemed more willing to employ environmentally friendly farming practices[63]. However, organic farmers in the Netherlands seemed less concerned than conventional farmers about keeping the farm in the family and claimed that continued farming was more important for society than for the family[25]. The highest ranked reasons to join nature conservation in a study by Ryan et al.[40] were to conserve the land for future generations and feeling attached to one's land.

According to the reviewed studies there are scattered and contradictory ideas on how farm size, farm history, farmer age and education, and heirs on the farm affect the farmers' willingness to perform nature conservation actions. The younger and more educated farmers often tend to be more business-minded and thus more willing to try new methods and management practices in conservation and management issues. This might lead to conflicting actions: more pesticides but also more conservation actions. The future of many farms is unknown since many of them lack heirs, but how this will affect nature conservation issues cannot be determined from the literature we consulted.

Discussion and Reflections

We have found in the literature that farmers are often characterized as independent, close to nature and the environment, and concerned about natural resources. Yet

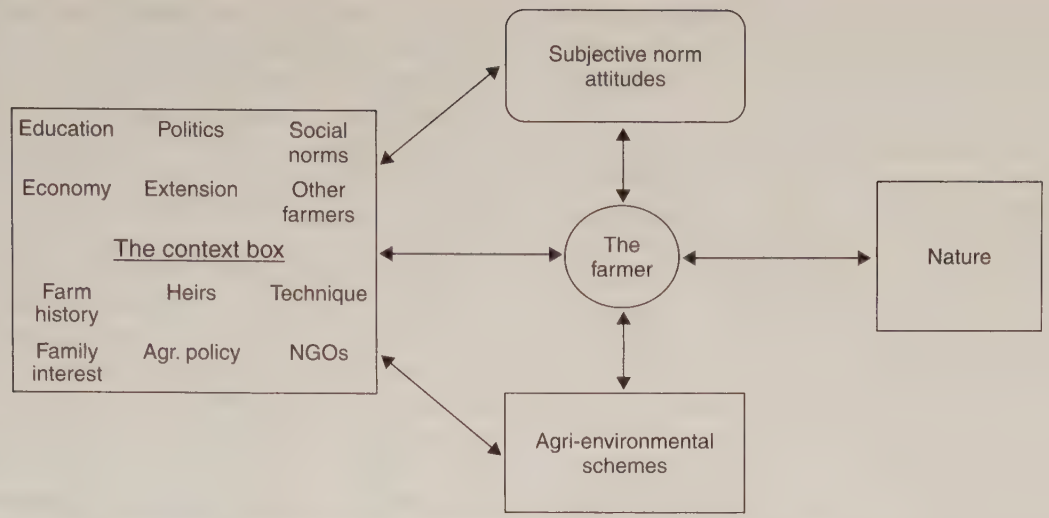

Figure 1. Attitudes and perceptions of farmers as affected by nature, context, and agri-environmental systems. The farmer is in the center of this model and thus the context box contains factors important for farmers. Deeper explanatory text to the model is included in the text.

this proximity to nature and natural systems does not necessarily seem to translate into a conservation ethic, nor does proximity to nature always result in farming practice and management decisions that are not primarily utilitarian. The interplay between the farmer and his or her context and attitudes and norms is more complex, which we illustrate by a model.

The model shown in Figure 1 consists of the farmer (age, sex, etc. included in this circle), his/her attitudes under everlasting and (fast) change depending on mood and situation (the reviewed literature captures these attitudes), nature and the farmer's effect on nature (attitudes change fast but the farming practices will not, thus there is a huge time lag between idea and change in behavior), the context box including several impacting factors, and finally the box with agri-environmental schemes. These schemes are a part of the context, but due to the focus of this article they are represented outside the context box to make it easier to see the connection to other parameters. We hope that our model can work as an eye-opener or a reminder to look outside the farm and inside the farmer when working with farming, agri-environmental schemes and nature conservation. We encourage policy-makers to consider the dynamics and complexity surrounding the farmer when making new, and applying present, agri-environmental schemes.

A farmer manages the farm to achieve certain goals, and to reach these goals certain means are used. The farmer has a certain perspective on the land and land-use, for example the farmer is aware of some changes and some issues in the current context (often technology, economy or policy) but is unaware of others (often nature conservation). The perspective of the farmer depends on how the farmer perceives the context in which he or she operates. Important context factors can be agri-environmental schemes, economics, extension, farm history, technology and social norms. Social norms are standards of behavior based on shared beliefs about how individuals should act[65] and are constituted when members in a group, in these case farmers, have expectations of how other members in the group think, believe, know and act. In line with social norms is social identity[66,67]—what social group the actor identifies with and thus what norms should be followed. In the review, we find a general, however vague, farmer identity but there are probably many farmer identities, defined either by the farmers themselves (e.g. milk producers, cereal growers, organic farmers, efficient farmers and traditional farmers) or defined by the surrounding society (e.g. old >60 years farmers, large >200 ha of arable land farmers and small scale <5 ha of arable land farmers).

The norms in the group are developed and maintained through interactions between the group members, and between groups and the rest of the context. The mindset of a farmer and feelings as a member, e.g. of the dairy farmers' group, is developed through comparison with other farmers in the group, other farmers outside the group and people outside the farming community.

When society tries to encourage the farmer to change management behavior, through politics via agri-environmental schemes, the farmer implicitly is offered a new identity and a new set of social norms. The changes in management can be challenged by the identity and the norms that the farmers already possess. There can be a great difference between social norms, actions approved by others; the subjective norm, the beliefs of what actions are approved by others; and attitudes and actions of the individual farmer[16,17]. In the study of Burgess et al.[68], farmers saw themselves as food producers. The subjective norm (attitude) is being a food producer, and thus their subjective norm (attitude) is working against the social norm suggested by nature conservation agencies, NGOs and the common opinion in society that the farmer should also be a conservationist. The enrollment process in agri-environmental schemes is thus a violation of the subjective

norm. Thus many farmers may be reluctant to join a scheme, but that does not necessarily mean that they do not want to provide conservation services, i.e. they balk at the form not the content.

All farmers also have personal attitudes. There are several definitions of attitudes, ranging from theoretical—attitudes are readiness to act[69], to operational—attitudes as they are measured in attitude tests. The fruitfulness of the very concept of attitudes has been debated by scholars[4]. Attitudes are neither permanent nor static and they are recreated each time we respond to a question, a behavior or a specific occurrence[70]. Thus, to conclude that a farmer has a certain attitude when it comes to management of the farm and nature is a pure speculation. In our theoretical model (Fig. 1), we use a theoretical definition of attitudes. We define attitudes as a readiness to act or a mindset that is used by an actor to act and judge in situations of decision-making. The literature that we have reviewed represents the attitudes the respondents each express in that specific interview or questionnaire situation. We want to stress that to express an opinion by heart, 'I see myself as a sustainable farmer' in an interview or to agree with a statement, 'Are your farming operations sustainable?' in a questionnaire demands different interpretations. To highlight this, attitudes are represented in our model (Fig. 1) by a box outside the farmer but in constant development by the farmer in interaction with his or her context. The attitudes are also outside the farmer to show that there can be a fast turnover of attitudes.

It is easy to express a wish to change the management of the farm to be more environmentally friendly but much harder and more time consuming to actually change behavior that ultimately has an impact on nature. The attitudes of the farmer are dependent on the norms that exist in the group/s that the farmer identifies with. From the reviewed literature, it seems to be a part of the farmers' norm to claim to be a steward of the land who cares for nature. However, if simultaneously asked how he or she wants to see and manage uncultivated areas, field islands, or riparian strips, the farmers' norms suggest an answer of tidy and clean habitats, which is behavior not promoting nature conservation and biodiversity. Attitudes cannot be studied as only personal parameters as they depend on the context, and especially social factors. This does not mean that every member in the group has an attitude corresponding to the group's attitude. Group members may have extreme opinions in comparison to others in the group, but still they depend on the group norms.

Farmers also act in correspondence with their experience of the physical prerequisites shown in the context box in Fig. 1: economics, social factors, knowledge and technology. If the farmer is unable to comply with the agri-environmental scheme due to these prerequisites, then extension and subsidies will have no effect. The important factor is how the farmer *perceives* his or her possibilities to act in accordance with the policies, laws and regulations. The farmer has to account for how he or she perceives the farm being affected by the change caused by the entry in agri-environmental schemes, for example:

- How the farm economy is affected by the change; what are the financial risks of joining; and how big a risk is he or she is willing to take?
- How the change will affect relations in the family, with other farmers and with neighbors.
- Does the farmer have enough knowledge to perform the management changes and whether or not he or she can judge the consequences of the changes for the farm?
- Can the farmer can get access to the technology needed for the change in management?

We identify three main ways to influence agriculture's effect on biodiversity: rules and regulations, financial incentives [e.g. subsidies such as agri-environmental schemes (AES), which also are conditioned to regulations] or better payment (branded production), and change in the mindset of farmers. The incentives can be explained in other words by people in nature conservation agencies. An example is pesticide use. 'You are not allowed to spray'; 'If you spray less, we compensate you for the yield loss' or 'We pay you more for your product if you spray less'. Or, 'We have problems with pesticide residues in the groundwater and this can affect the water quality in your own well'. If explained from the farmer perspective, it may be quite different. 'I am not allowed to spray and I am obliged to and want to follow the law'. 'Since my yield loss is compensated I spray less' or 'Since I get higher price for my product I spray less', 'I see my use of pesticides as part of the problem with pesticide residues in the groundwater and later in my drinking water, and so I will try to find alternative methods and/or spray only when it is really needed'.

Subsidies can be a starting point to change farmers' thinking, especially if combined with education and extension. Kleijn and Sutherland[6] state that programs where the payment is reasonable and a scheme promotes the farmers' knowledge and increases positive feelings for the habitat or action, then the likelihood of a long-term success is higher. Aldo Leopold has expressed the same idea in the following words: 'Once you learn to read the land, I have no fear of what you will do to it, or with it. And I know many pleasant things it will do to you'[71].

Development of New AES

Good stewards adapt to changes and develop their management units according to their experiences and attitudes towards the land. Nordström Källström and Ljung[72] state that many farmers perceive the lack of control of the decision-making process for the farm as the most important factor that hinders their ability to continue farming. Farmers often do not feel empowered to initiate modifications of farm management, and feel stifled by rigid requirements that turn out to be detrimental to adoption of schemes if there is little flexibility. We agree that '... by

adopting a more inclusionary and participatory approach, conservation (in the UK and elsewhere) can benefit both wildlife and people in ways that currently appear to be precluded by the dominance of a scientific approach (non-inclusive and participatory)'[73]. The agri-environmental schemes ought to be so flexible that farm-specific solutions can be allowed if they can help fulfill the goals and follow the principles of the scheme. As Davis[34] said, 'Don't fall in love with your computer, or with your guides, or with your standards [agri-environmental schemes] . . .'.

It is not the fulfillment of each and every detail of the scheme that is important but the fulfillment of the overall aims of the schemes. Unfortunately, today it seems as if the dominating opinion is that rigid schemes are easier to evaluate and control, and therefore they are widely used. However, by trying to fit schemes to administration rather than to nature and people we lose the ability of local adaptations and thus the possibility to create truly effective agri-environmental schemes. Leopold puts it in another way in his book about land ethics: 'In our attempt to make conservation easy, we have made it trivial'[71].

Concluding Remarks

The results from the literature sometimes contain both contradictions and paradoxes. The literature shows a great diversity of attitudes and, since attitudes are not static, change even within an individual and among individuals will differ, thus generalizations are hard to make. We agree with Burton[17] that there appears to be an over-confidence in attitudes as a main driver of action, and there is also an unsound belief in the power of attitude studies to reveal the true intentions of stakeholders. However, since farmers impact conservation practices and decisions, incorporating some of the knowledge from attitude studies in the design of new agri-environmental schemes is likely to be better than giving no consideration to the 'soft values' expressed by farmers.

Further research must be able to handle paradoxes and embrace rather than shrink back from them. The combinations of scientific disciplines are one way to deal with paradoxes. Research design must include ample time, since for example several meetings with the same farmer will increase the probability of uncovering paradoxes in farm management and nature conservation. Economics of the farm will often be mentioned in the interviews but if the interview technique allows several meetings then other reasons and explanations will appear[4]. We hope that coming research and publications will spread more light over the complex reality of farming and conservation in the agricultural landscape, and help us understand better how farmers' attitudes shape compliance with environmentally driven subsidy goals.

Acknowledgements. We thank J. Bengtsson, J. Björklund, two anonymous referees and the editors for valuable comments on the manuscript. FORMAS, Ekhaga Foundation and Oscar and Lili Lamm's foundation have given financial support to the first author.

References

1 Benton, T.G., Bryant, D.M., Cole, L., and Crick, H.Q.P. 2002. Linking agricultural practices to insect and bird populations: a historical study over three decades. Journal of Applied Ecology 39:673–687.
2 Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R., and Carter, N. 1995. Population declines and range contractions among lowland farmland birds in Britain. Conservation Biology 9:1425–1441.
3 Krebs, J.R., Wilson, J.D., Bradbury, R.B., and Siriwardena, G.M. 1999. The second silent spring. Nature 400:611–612.
4 Siebert, R., Toogood, M., and Knierim, A. 2006. Factors affecting European farmers' participation in biodiversity policies. Sociologia Ruralis 46:318–340.
5 Kleijn, D., Berense, F., and Gilissen, N. 2001. Agri-environmental schemes do not effectively protect biodiversity in Dutch agricultural landscapes. Nature 43:723–725.
6 Kleijn, D. and Sutherland, W.J. 2003. How effective are European agri-environmental schemes in conserving and promoting biodiversity? Journal of Applied Ecology 40:947–969.
7 Knop, K., Kleijn, D., Herzog, F., and Schmid, B. 2006. Effectiveness of the Swiss agri-environmental scheme in promoting biodiversity. Journal of Applied Ecology 43:120–127.
8 Carey, P.D., Manchester, S.J., and Firbank, L.G. 2005. Performance of two agri-environmental schemes in England: a comparison of ecological and multi-disciplinary evaluations. Agriculture, Ecosystems and Environment 108:178–188.
9 Bengtsson, J., Ahnström, J., and Weibull, A.-C. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology 42:261–269.
10 Mattison, H.A. and Norris, K. 2005. Bridging the gaps between agricultural policy, land-use and biodiversity. Trends in Ecology and Evolution 20:610–616.
11 Benton, T.G., Vickery, J.A., and Wilson, J.D. 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution 18:182–188.
12 Firbank, L.G. 2005. Striking new balance between agricultural production and biodiversity. Annals of Applied Biology 146:163–175.
13 Feehan, J., Gillmor, D.A., and Culleton, N. 2005. Effects of an agri-environmental scheme on farmland biodiversity in Ireland. Agriculture, Ecosystems and Environment 107:275–286.
14 Smallshire, D., Robertson, P., and Thompson, P. 2004. Policy into practice: the development and delivery of agri-environmental schemes and supporting advice. IBIS 146:250–258.
15 Toogood, M., Gilbert, K., and Rientjes, S. 2004. Farmers and the environment. Assessing the factors that affect farmers' willingness and ability to cooperate with biodiversity policies. Biofact, European Centre for Nature Conservation, Wageningen, the Netherlands.
16 Fishbein, M. and Ajzen, I. 1975. Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research. Addison-Wesley, Reading, MA, USA.

17 Burton, R.J.F. 2004. Reconceptualising the 'behavioural approach' in the agricultural studies: a socio-psychological perspective. Journal of Rural Studies 20:359–371.
18 Sullivan, S., McCann, E., De Young, R., and Erickson, D.L. 1996. Farmers' attitudes about farming and the environment: a survey of conventional and organic farmers. Journal of Agricultural and Environmental Ethics 9:123–143.
19 Trembley, K.R. and Dunlap, R.E. 1978. Rural-urban residence and concern with environmental quality: a replication and extension. Rural Sociology 43:474–491.
20 Westmacott, R. 1983. The conservation of farmed landscapes: attitudes and problems in the United States and Britain. Landscape Design 144:11–14.
21 Hanson, J.C., Kauffman, C.S., and Schauer, A. 1995. Attitudes and practices of sustainable farmers, with applications to designing a sustainable agricultural program. Journal of Sustainable Agriculture 6:135–156.
22 Liffman, R.H., Huntsinger, L., and Forero, L.C. 2000. To ranch or not to ranch: home on the urban range? Journal of Range Management 53:362–370.
23 Bieling, C. and Plieninger, T. 2003. 'Stinking, disease-spreading brutes' or 'four-legged landscape managers'? Livestock, pastoralism, and society in Germany and the USA. Outlook on Agriculture 32:7–12.
24 McGregor, M.M., Willock, J., and Deary, I.J. 1995. Farmer stress. Farm Management 9:57–65.
25 Schoon, B. and Te Grotenhuis, R. 2000. Values of farmers, sustainability and agricultural policy. Journal of Agricultural and Environmental Ethics 12:17–27.
26 Duram, L.A. 1999. Factors in organic farmers' decision making: diversity, challenge, and obstacles. American Journal of Alternative Agriculture 14:2–9.
27 van der Meulen, H.A.B., de Snoo, G.R., and Wossink, G.A.A. 1996. Farmers' perception of unsprayed crop edges in the Netherlands. Journal of Environmental Management 47:241–255.
28 Oreszczyn, S. and Lane, A. 2000. The meaning of hedgerows in the English landscape: different stakeholder perspectives and the implications for future hedge management. Journal of Environmental Management 60:101–118.
29 Brook, A., Zind, M., and DeYoung, R. 2003. Landowners' responses to an endangered species act listing and implications for encouraging conservation. Conservation Biology 17: 1638–1649.
30 Harrison, C.M., Burgess, J., and Clark, J. 1998. Discounted knowledges: farmers' and residents' understandings of nature conservation goals and policies. Journal of Environmental Management 54:305–320.
31 Battershill, M.R.J. and Gilg, A.W. 1996. New approaches to creative conservation on farms in South-west England. Journal of Environmental Management 48:321–340.
32 Clark, J. and Murdoch, J. 1997. Local knowledge and the precarious extension of scientific networks: a reflection on three case studies. Sociologia Ruralis 37:38–60.
33 Skelton, P., Josiah, S.J., King, J., Brandle, J.R., Helmers, G., and Francis, C.A. 2005. Adoption of riparian forest buffers on private lands. Journal of Small-Scale Forest Economics, Management, and Policy 4:185–204.
34 Davis, R.M. 1985. Conservation: a matter of motivation. Journal of Soil and Water Conservation 40:400–402.
35 Morris, C. and Potter, C. 1995. Recruiting the new conservationists: farmers' adoption of agri-environmental schemes in the UK. Journal of Rural Studies 11:51–63.
36 Coleman, D., Crabtree, B., Round, J., and O'Carrol, L. 1992. Comparative Effectiveness of Conservation Mechanisms. Manchester University, UK.
37 Silvasti, T. 2003. The cultural model of 'the good farmer' and the environmental question in Finland. Agriculture and Human Values 20:143–150.
38 Beedell, J.D.C. and Rehman, T. 1999. Explaining farmers' conservation behavior: why do farmers behave the way they do? Journal of Environmental Management 57:165–176.
39 Fairweather, J.R. and Campbell, H.R. 2003. Environmental beliefs and farm practices of New Zealand farmers: contrasting pathways to sustainability. Agriculture and Human Values 20:287–300.
40 Ryan, R.L., Erickson, D.L., and De Young, R. 2003. Farmers' motivations for adopting conservation practices along riparian zones in a Mid-western agricultural watershed. Journal of Environmental Planning and Management 46:19–37.
41 Carr, S. and Tait, J. 1991. Differences in the attitudes of farmers and conservationists and their implications. Journal of Environmental Management 32:281–294.
42 Wicker, A.W. 1969. Attitudes versus actions: the relationship of verbal and overt behavioral responses to attitude objects. Journal of Rural Studies 11:51–63.
43 Millar, J. and Curtis, A. 1999. Challenging the boundaries of local and scientific knowledge in Australia: opportunities for social learning in managing temperate upland pastures. Agriculture and Human Values 16:389–399.
44 Vanclay, F. 1992. The social context of farmers' adoption of environmentally sound farming practices. In G. Lawrence, F. Vanclay, and B. Furze (eds). Agriculture, Environment and Society. Macmillan, Melbourne, Victoria, Australia.
45 McCann, E., Shannon, S., Erickson, D., and Young, R.D. 1997. Environmental awareness, economic orientation, and farming practices: a comparison of organic and conventional farmers. Environmental Management 21:747–758.
46 Storstad, O. and Bjørkhaug, H. 2003. Foundations of production and consumption of organic food in Norway: common attitudes among farmers and consumers? Agriculture and Human Values 20:151–163.
47 Pyrovetsi, M. and Daoutopoulus, G. 1999. Farmers' need for nature conservation education in Greece. Journal of Environmental Management 56:147–157.
48 Willock, J., Deary, I.J., McGregor, M., Sutherland, A., Edwards-Jones, G., Morgan, O., Dent, B., Grieve, R., Gibson, G., and Austin, E. 1999. Farmers' attitudes, objectives, behaviors, and personality traits: the Edinburgh study of decision making on farms. Journal of Vocational Behavior 54:5–36.
49 Gasson, R. and Potter, C. 1988. Conservation through land diversion: a survey of farmers' attitudes. Journal of Agricultural Economics 39:340–351.
50 Dick, R. 1992. Sustainability, can it be measured in agricultural systems? Fourth North American Symposium on Society and Resource Management, Madison, WI, USA.
51 Westmacott, R. and Worthington, T. 1984. Agricultural Landscapes: A Second look. Countryside Commission, Cheltenham, UK.
52 Trout, S.K., Francis, C.A., and Barbuto, J. Jr 2005. Impacts of the North-Central Region SARE grants, 1988–2002. Journal of Sustainable Agriculture 27:117–137.
53 Buttel, F.H. and Gillespie, G.W. Jr 1988. Preferences for crop production practices among conventional and

alternative farmers. American Journal of Alternative Agriculture 3:11–17.
54 Filson, C.G. 1993. Cooperation differences in Ontario farmers' environmental attitudes. Journal of Agricultural and Environmental Ethics 6:165–184.
55 Albrecht, D.E. and Murdock, S.H. 1990. The Sociology of U.S. Agriculture: An Ecological Perspective. Iowa State University Press, Ames, IA, USA.
56 Traore, N. 1998. On-farm adoption of conservation practices: the role of farm and farmer characteristics, perceptions, and health hazards. Land Economics 74:114–128.
57 Featherstone, M.A. and Goodwin, B.K. 1993. Factors influencing a farmer's decision to invest in long-term conservation improvements. Land Economics 69:67–81.
58 Bultena, G.L., Nowak, P., Hoiberg, E., and Albrecht, D. 1981. Farmers' attitudes toward land use planning. Journal of Soil and Water Conservation 36:37–41.
59 Bultena, G.L. and Hoiberg, E.O. 1983. Factors affecting farmers' adoption of conservation tillage. Journal of Soil and Water Conservation 38:281–284.
60 Jacobsen, R.M., Youngs, G.A. Jr, Goreham, G.A., Watt, D.L., Dahl, B.L., Sell, R.S., and Stearns, L.D. 1991. Selected characteristics of North Dakota farm families engaged in sustainable agricultural practices. Agricultural Economics Report No. 271. Department of Agricultural Economics, North Dakota State University, Fargo, ND, USA.
61 Carlson, J.E. and McLeod, M.E. 1977. Farmers' attitudes toward soil erosion and related farm problems in the Lewis and Idaho county wheat region. Progress Report No. 198. University of Idaho, Moscow, ID, USA.
62 Gould, W., Saupe, W.E., and Klemme, R.M. 1989. Conservation tillage: the role of farm and operator characteristics and perception of soil erosion. Land Economics 65:167–181.
63 Wilson, G.A. 1996. Farmer environmental attitudes and ESA participation. Geoforum 27:115–131.
64 Segalen, M. 1987. Objets domestiques de la vie ouvrière. Transmissions et ruptures dans les familles de Nanterre (1920–1960). Ethnologie Française 17:29–38.
65 Fehr, E. and Fischbacher, U. 2004. Social norms and human cooperation. Trends in Cognitive Sciences 8:185–190.
66 Tajfel, H., Billig, M.G., Bundy, R.F., and Flament, C. 1971. Social categorization and intergroup behaviour. European Journal of Psychology 1:149–177.
67 Tajfel, H. (ed.). 1982. Social Identity and Intergroup Relations. Cambridge University Press, Cambridge, UK.
68 Burgess, J., Clark, J., and Harrison, C.M. 2000. Knowledge in action: an actor network analysis of a wetland agri-environmental scheme. Ecological Economics 35:119–132.
69 Jung, C.G. [1921] 1971. Psychological Types, Collected Works, Volume 6. Princeton University Press, Princeton, NJ, USA.
70 Eagly, A.H. and Chaiken, S. 1993. The Psychology of Attitudes. Harcourt Brace, Orlando, FL, USA.
71 Leopold, A. 1949. A Sand County Almanac and Sketches Here and There. Oxford University Press, NY, USA.
72 Nordström Källström, H. and Ljung, M. 2005. Social sustainability and collaborative learning. Ambio 34:376–382.
73 Harrison, C. and Burgess, J. 2000. Valuing nature in context: the contribution of common-good approaches. Biodiversity and Conservation 9:1115–1130.

Renewable Agriculture and Food Systems: 24(1); 48–59 doi:10.1017/S1742170508002408

Farming systems education: Case study of Swedish test pilots

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Accepted 15 August 2008; First published online 8 December 2008 **Research Paper**

Abstract

We describe and analyze a pedagogical experiment that introduced a broad and holistic perspective on complete farming systems, systemic learning tools, and a participatory learning strategy at an early stage in agronomy education. The paper describes the adventure of three students, who came from a conventional agronomy program at the Swedish University of Agricultural Sciences (SLU), who were frustrated with the lack of integrated approaches to the study of agricultural systems and a strong focus on molecular-level processes in their first year of education. They encountered a narrow focus in most courses and the overall curricula of agricultural education that is a function of specialization and university organization in unique departments that concentrate on small pieces of the large puzzle, that is the production milieu. In the current educational environment, it is difficult for students to make connections, integrate information and theories, and to create relevance to the challenges they observe in the practical world of farming and food systems. The three students agreed to put on pilots' costumes and climb into an experimental vehicle called *experiential learning*, one that provides *just-in-time education* and a very high degree of self-responsibility for the learning process. The paper describes, analyzes, and evaluates the comprehensive and exhausting pedagogical process they followed in one semester in Sweden and Viet Nam, with positive and negative aspects of the program. We provide reflective recommendations from students and advisors for future agronomic education programs with the focus on developing renewable agriculture, selecting students and evaluating performance, and designing practical programs that will motivate highly committed and action-oriented students.

Key words: experiential education, action learning, rural development, sustainable agriculture, Viet Nam, Sweden

Introduction

There is growing concern about the limited attention given to systems studies in agricultural education and training on one hand, and on the other hand *how* farming and food systems are interpreted as systems: as complex, open, interactive, developing, self-organizing systems, or as closed mechanical systems at equilibrium. These two kinds of problems need to be given much more attention in our agricultural universities: (1) what hierarchical scale will be the focus in the study program, and (2) what kind of theories and tools shall the students be exposed to in their education and learning process to be able to develop as professionals in understanding, describing and designing responsible action in farming and food systems?

A third problem we see in agricultural education today is a lack of motivation and inspiration for taking the conventional curricula, especially for an increasing number of students without any previous experience in agriculture. Students in agricultural universities normally major in agronomy, entomology, animal science, agricultural economics or other specific discipline. They rarely are faced with the challenge of how this new and specialized knowledge fits into the context of whole systems, nor into the context of the farm and food chain. In addition, many of our agriculture students today arrive without a farm background, further adding to the difficulty of their creating relevance from study of isolated disciplines. Here, we use the definition of academic discipline expressed by Odum[1]: 'A discipline can be defined as a set of people studying the same scale of science with shared models of performance.' We are quickly moving away from providing society with well-educated generalists who can contribute to whole systems, thinking and acting as facilitators for improving problematic situations with inherent goal conflicts, and instead today we are preparing disciplinary 'problem solvers' in isolated

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systems. Further, we contend that even specialists who are well prepared in one narrow area will be less capable of identifying challenges in production systems in an uncertain and rapidly changing future[2]. Education in the emerging area of agroecology is designed to correct this deficiency.

Agroecology has generally been considered to be the marriage of agriculture and ecology[3,4]. It can also be defined as the *ecology of food systems*[5], to include the study of production, economics, environment and natural resources, and social implications of farming and food systems. The latter definition provides a foundation for a systemic view and study of the whole, where societies and nature are integrated parts of the same open, interactive and constantly changing system. Some of the new courses in this area are guiding students through a learning landscape that gives a broad appreciation of the challenges of current systems as well as a learning space for envisioning new systems that will be productive and economically sound, preserve and enhance the natural resource base through dependence on renewable energy and internal resources on the farm, and provide relevant and equitable contributions to food supply and society. Also important are farming impacts on essential ecosystem services that are neither recognized nor rewarded in today's industrial farming and economic system[6]. An agroecology education is designed to develop a new generation of agroecologists prepared to deal with complexity and change[7], and at a relevant chosen scale[1] (in time and space) that fits the complex problematic situation to be scrutinized and improved.

We have observed that some students who enter the agricultural university to learn about food production and food systems quickly become disillusioned by an education that is subdivided into components, and a curriculum that makes it difficult to see the whole system and ways to improve it. They are placed in courses such as introductory chemistry or calculus that appear to have little relevance to what they want to learn and apply in the future. One could say that they are neither ready to put this information into context (both in scale and in systems perspectives – systems seen as mechanical systems or seen as self-organizing systems[1]), nor are they provided with much help in establishing the importance of subject matter to real world situations[8]. Not satisfied with our assurances that they will understand later how it all fits together, some highly motivated students leave the study of agriculture to pursue other endeavors. They are impatient with the rather fixed establishment in education, and choose to pursue their own goals and methods to achieve them.

It is in this environment of limited systems orientation to agricultural education, and dissatisfaction of students with the current subjects and sequence of courses, that we are searching for alternatives. One innovative program introduced in 2006 in Sweden was an independent study option that put responsibility for design of one semester's learning agenda in the hands of the students, with guidance from senior faculty with much experience in farming systems. In this paper, we describe the background and objectives of the program in experiential learning, the methods used in Sweden and Viet Nam by students who designed their own practical course in farming systems analysis, the results of their field observations and interviews with farmers and others in the food system, the students' reflections on this type of learning and specific experience, and the potentials and limitations of introducing such an opportunity into the study of agricultural systems in our universities. We summarize and evaluate the experience and provide conclusions about whether this will become a meaningful option for more students in the future.

Experiential Learning

John Dewey[9] was one of the first in professional education to insist that experience was the basis for learning, and recommended that teaching should be done in a way that will imbed new knowledge in the prior experience base of students. In some ways this is akin to learning to ask the right questions, an approach attributed to Socrates and more recently popularized in the book *Ishmael* by Daniel Quinn[10]. It could be argued that students who are conditioned by the time they reach the university to be passive learners, captives in classrooms designed for one-way transfer of information or observers in front of a video screen, are seriously in need of a transformation that will turn them into active learners. Jack Mezirow[11] provided an insight on how students build understanding from the contexts already familiar to them, and why both teachers and students should clarify their experiences, expectations and assumptions in order to design an effective learning environment.

This philosophy is being discussed and implemented under the term 'action learning' that implies some application of theory outside the often context-free environment of the classroom[12–14]. In agriculture, we interpret this to be hands-on experience, not only outside the classroom and into the field, but preferably working with clients in the farming and food system. It is a learning process put into practice in the Hawkesbury experience in Australia[15], in the summer travel courses in agroecosystems analysis in the US Midwest[16], and in an agroecology class on campus that reaches out with projects in the community[17]. Students quickly learn that many of the constraints are not just only soil fertility or pests in the field, but uncertain crop prices in the marketplace, and environmental regulations that must be considered. The social dimension, including labor, farmer goals and financial situation, family needs, and linkages with neighbors and the rural community, are key factors in farming system design and choice of enterprises. A consequence of this experiential learning approach is also that the system perspective in use must be adapted to the real situation instead of moving the system into another 'controlled' environment in a laboratory or computer simulation. That is, the students are facing complex situations and have to find relevant perspectives, theories and tools for a system that is complex, open, interactive with its surroundings and under constant change and development.

The Norwegian masters degree courses in agroecology start on the first day with practical experience on the farm[18], which in effect is a practical application of the principles used in research using phenomenology[19]. With experience as instructors and students in agriculture, we have become highly motivated by this immediate exposure to real-world systems, both in farming and in the food system. Learning about mixed farming by walking the fields through the mud, interacting with livestock and dodging manure in the pasture, hearing and seeing and smelling the stimuli that are part of the farm environment can be a transforming experience in understanding complexity and interactions of a near-infinite number of factors that influence farming success. It can also create an extremely efficient foundation for reflection and theoretical analyses of an open, interactive, developing and complex system later on in the class. Interviewing processors, conversing with shop keepers, accompanying government agriculture officials in their work and conducting focus groups with consumers brings us closer to the human food web in all its complexity. The experience also gives the students a flavor of their future work environment and challenges as professionals. When we look at the complexity of the process of moving food from field to table, we recognize quickly that this is a web of material and information exchange among different actors in the system. It becomes easy to see that the web cannot be complete without recycling of wastes from the system, including human waste, in order to close some of the nutrient cycles and make the system more sustainable. It also becomes easy to see potential goal conflicts between different actors in implementing such recycling systems. We conclude that this type of experience linked with formal education brings meaning and excitement to the learning process, and opens up the perspectives for the student on the processes and interactions in open systems under constant change. How can students participate in this planning process?

Methods

Planning process

The concept of test pilots was born out of the concerns of some Swedish students in their first semester (autumn 2005) who felt locked into a fixed curriculum that did not have the excitement and relevance they expected upon coming to the university and starting an agronomy program. Based on narrowly focused courses with specific knowledge and theories taught in the context of the classroom, this curriculum had pushed them to seriously consider leaving the university to pursue other careers. The challenge of designing their own courses and learning activities that seemed meaningful to them was an opportunity they were willing to try as an experiment for one semester. In the initial meeting, at the end of their first autumn semester of the agronomy program, there were ten interested students; in the second meeting eight returned for more information and discussion. In the months leading up to the start of the course there were five seriously interested, and just before the summer vacation 2006 three actually put on their pilot's costumes and climbed into the experimental vehicle. All were highly motivated to try a new approach to independent education, with a guarantee that their credits could be used to fill the free elective courses that were part of their conventional educational curriculum.

Two instructors with years of background in experiential learning in agroecology and agroecosystems analysis were equally concerned about the availability of courses for undergraduates that would provide field experiences, learning in context, and multidimensional evaluation of farming and food systems. Their prior organization of PhD and MSc courses provided indications that guided learning in practical systems could result in highly motivated students who went on from those courses with a much broader perspective and a capacity to plan and deal with uncertainty and complexity in systems[20,21]. Instructor and student enthusiasm carried agroecology students forward through their other classes and into a thesis project that reflected an appreciation of the systems approach and an ability to use both hard systems and soft systems methods. Although the faculty participants had experience guiding students in project work in undergraduate and graduate courses, they had not provided the opportunity for students to design their own course in a completely open-ended manner, nor with undergraduate students so early in their university training. The test pilot idea provided just such an opportunity.

The three students who agreed to test this model moved away from the prescribed courses in their traditional crop science sequence in their third semester of the agronomy program. They felt that this project should provide an opportunity for individual growth, experience with a small team of students who would set their own objectives and course expectations, and space to explore ideas about integrated farming and food systems that would transcend discipline lines and give a more complete picture of the entire, dynamic system. In the course planning, the students communicated a strong interest to study both Swedish farming systems as well as farming systems in developing countries. The semester was therefore divided into two courses, the first with a focus on the Swedish farming sector near Uppsala in east central Sweden, and the second course with perspectives, theories and tools for analyzing farming cases in developing countries, using An Giang province in the Mekong Delta in Viet Nam as the case study. Funds for travel and support for the travel experiences were provided by the department's reallocation of resources from the course budget, and from the students' own savings.

Course structure

The courses were designed as a tentative first semester for agronomy students, with the overall aim to create a learning environment for learning and training to *read the agricultural context*, both in Sweden and in another country in

the global South. The Swedish agricultural systems were studied in a course designed by students that was called *Analyzing Swedish Farming Systems*, with the practical experience taking place near the campus in Uppsala on two farms. One was an organic farm with mixed animal stocking, hens, pigs and beef cows, and total 100 ha farmland and 60 ha forest. The other farm was a conventional stockless farm of 800 ha farmland. Students also visited agencies and institutions related to the food system in Sweden. This was the first half of the autumn semester in 2006. As an introductory core book on Swedish farming systems, the students read *Organic farming, crop and animal husbandry* (Swedish title *Ekologiskt lantbruk, odling och djurhållning*) by Inger Källander[22] who is an organic farmer and leader in alternative farming. Most important for this course, the book integrates cropping, animal husbandry and farming economics in a more holistic way than traditional Swedish books in agronomy. Along with this book, the students read other references they discovered and some recommended by other actors in the food system during this educational journey.

The course design was set up as a sequence of 'events' to create a learning environment on new aspects and perspectives on agricultural contexts. One new aspect or thematic area of farming systems was introduced each week through literature reading, sometimes supplemented by watching a movie, all organized by the students with the instructor as a facilitator. Literature readings were followed by interaction about a case situation, for example the two Swedish farms used as references through the whole course, study visits to agricultural businesses or state/local institutions, and discussions with invited specialists in the Swedish food web. Students processed the literature study and the case study together in group work. The learning process of the thematic area was finally discussed in a feedback session with teachers and students together at the end of each week.

First course process and content

The thematic areas covered in the first course included:

- Working in groups using appropriate tools for efficient group action and reflections, which we consider essential for student-driven courses to be successful.
- Approaching farming systems as integrated human and natural systems, also introducing mind mapping as a tool.
- Gaining data and information by dialogue and interviewing, while also introducing some very basic interview techniques.
- Developing perspectives on nature as related to interactions with farming systems.
- Exploring gender perspectives, a key factor often overlooked in conventional studies of production and economics.
- Anticipating agriculture after peak-oil, with all the adjustments that will be necessary in production practices and reduced energy use.
- Exploring agriculture as a self-organizing system, similar to general principles in ecological and other biological systems, but including humans as managers of enterprises and system design.
- Integrating perspectives from different actors in the food web, including interviews of people from the National Food Administration, Swedish Board of Agriculture, and different small-scale food processing business ventures, farmers unions, and environmental NGOs.

The different categories of perspectives covered in the first half of the semester course were:

- Perspectives of the farmer family, including the farmer's and farm family member's motivations for farming, 'internal' and 'external' motivations, connectedness and dependency of biophysical elements with the economy and institutions, and traditions, norms and values that influence farming decisions.
- Production perspectives, including basic crop production and animal husbandry, production systems planning from sowing to harvesting and from calf to cow, alternative production systems, organic certification, and strategies and goal conflicts in production versus conservation.
- Economic perspectives, including the overall economy of a farm, money flows out from and into the farm, overview of the tools used for administering diversity and sustainable, holistic policies, and investment strategies and financial sources from the farmer's point of view.
- Perspectives on institutions, including rules, regulations, and subsidies that highly influence farming practices and planning, local norms and values, certification organizations, institutional hierarchies, e.g. municipal, county, state, EU, WTO.
- Systems ecology perspective, including a historical vision, the farming system's resource base and the farmer's time and space scales, ecosystem services, control versus dynamic adaptation and following natural principles, role of unpredictable events and system resilience, and farmer creativity in dynamic development processes of self-organizing systems.

Second course process and content

For the second half-semester course the course goals were both to expand the perspective of food web to include aspects of globalization of the food system, and to learn how to read a farming context in a country in the global South (the so-called 'Developing Countries'). The first part of this course focused on perspectives, theories and tools. Learning goals were for preparing students to be able to approach the agricultural context in an entirely new situation and:

- describe key concepts and principles of the globalized food chain;
- identify and relate the interactions with and dependency of the food chain on both the biogeosphere and local society;

- describe the roles of some key actors in the globalized food chain scene;
- apply interdisciplinary methods and tools, in a qualitative way, to describe and analyze and then suggest improvements to sustainability of the food chain; and
- use concepts and methods in an independent way to read contexts of different concrete areas for actors in the food chain.

The course started with literature readings on global food systems, and selected lectures from other university courses and conferences that were relevant to the subject. The literature readings and lectures were processed in group meetings, and opportunity was provided for feedback from teachers.

Students rather quickly decided that it would be more meaningful to see systems in the developing world 'up close and personal'. They felt that reading and discussing agriculture, food systems, and hunger in the relative comfort of a Swedish university and at a long distance from these actual systems in the field was not the best way to learn about them. It was not a realistic use of the potentials of an experiential education.

In the second half of the course, the field section, students decided to travel and gain first-hand experience in another part of the world. For this activity, the goals included preparing students to be able to:

- demonstrate skills in analyzing agricultural systems, at a farm and family level, in a project format;
- present how the studied farming system is connected to and is influenced by the global food system, and prepare this in written and/oral form; and
- apply interdisciplinary methods and tools to describe and analyze sustainable aspects of the case study in a qualitative way.

In terms of content, the course was designed for students to learn, practice and apply:

- different tools of Participatory Rural Appraisal (PRA) and Rapid Rural Appraisal (RRA) such as building a rich picture, VENN diagramming, seasonal activity calendars, mapping, scoring and transect walks;
- systems diagramming using energy flow and other measures of efficiency; and
- reflection on the field studies with respect to the conditions for food production in a location outside Europe, including the resource base, biological potential, agronomic practices and socio-economic situation, and how all these factors interact.

The field work was carried out in Viet Nam, within the bilateral co-operation in a Viet Nam–Sweden network for research and education (called RDViet, see http://www.rdviet.net/) and especially within the co-operation between Hue University and SLU within this network. In Viet Nam, the students studied and documented different kinds of farming systems and their dependency on local and external resources, and how they were connected to different kinds of markets (self-sufficient households and local, national and global markets). In the first phase of the students' Viet Nam visit, they were integrated into some of the teaching topics in an ongoing masters program course in rural development, a program set up as a co-operation between Hue University and SLU. After this three-week course training in Hue, the students traveled to the Mekong Delta and the University of An Giang. The students planned the culmination of the course as a two-week travel, observation, and interviewing experience with interpreters in two different villages in the *An Giang* Province in the Mekong Delta. They visited a village called *My Luong Commune* in the *Cho Moi* District; the second was an ethnic Khmer community, *O Lam Commune* in the *Tri Ton* District. Both were rice-growing communities, and had both irrigated and rainfed crops, with the latter more prevalent in the Khmer community in the uplands. Working with translators from the nearby agricultural university, students visited the two villages and used PRA tools and Farming Systems Diagraming[23] which combined interviews with farmers and leaders in the community, and evaluation techniques for facilitating development by working with local people. The tools were used for mapping villages and their resources, irrigation systems and other infrastructure, and then in describing the farming systems and estimating economic activity. There was also attention given to the environmental resources and impacts of farming and social relationships in the communities that impacted the production and food systems.

Specific tools used in group discussions with ten farmers in each village included developing a rich picture of the community and food system, based on opinions and information from people in the village, and a season calendar of farming and food-related activities. From these, some scoring of production, economics, and social relationships was possible. Individual farmer interviews were accomplished with a rich farmer, a medium-income farmer, and a poor farmer in each village. Specific tools used in interviews of these farmers were developing a rich picture of the farm, a Venn diagram to use symbols to show relationships between household and community, and rankings of production, economics and social relationships of the family with the community. The families to be interviewed were selected by the village leader with help from the university interpreters. There were four interpreters who accompanied the students to the *My Luong* village, and an additional Khmer-speaking interpreter was added for the visit to *O Lam* village.

The modest set of materials used during the interviews and interactive process with farmers and families included large papers for drawing, colored markers, scissors and tape. Cameras, notebooks and pens were used for note taking and documentation. There were small gifts of fruit, candy, cigarettes and water for the farmers, to recognize and reward their time shared with the student team during the interviews. The farmers in the group discussion were invited for a lunch together with the students and staff from the university.

During the village visits, students were able to identify

- the principal crops and cropping systems,
- the principal issues related to soils and soil quality,
- the issues related to poverty and potential for new markets,
- the changes in policy and economics that changed the focus of farmers from quality products to maximum quantity of production,
- the promise of future markets based on quality and value adding in the community,
- the potentials of cooperatives to improve the economic situation of farmers and families, and
- the expected changes in local village economies as a result of the pending decision to join WTO.

General observations during the travel and village visits and interviews included

- details on the functioning of the extremely hierarchical extension system,
- the role of livestock today and its potential for the future,
- the prevalence of waste in the countryside, especially plastic,
- the history of agricultural policy and its impacts, and
- the future perspectives for Viet Nam agriculture with the pending entry into the WTO.

We recognize that the results presented from a comparison of two Swedish farms and the short visits to two villages in Viet Nam provide only a snapshot of the total agricultural situation and complexity in two countries, yet it does give us an insight into the plight of a rural population in both a developed and a developing country today, the impacts of international economics and politics, and the potentials for people to operate in a complex world. It also shows that the learning environments created in this one semester for reading the agricultural context were highly effective in supporting experiential education. The students' capacity to read complex agricultural contexts has developed to a rather high level during these two courses, and indicates the possibility of introducing complex cases as a basis for learning systemic analysis and systems thinking at an early phase of university studies.

Learning goals and evaluation

In the development of the test pilot experience, we were interested in learning how well students early in an agronomy career could take major responsibility for design of their own learning landscape, with guidance from instructors. Both students and instructors were concerned about the intensity of the planning and learning experience, and whether the investment of additional energy on the part of both groups would result in successful learning. We also wanted to learn how this experience would compare with a full semester of courses in a conventional, on-campus class environment. The investment in faculty time with a small number of students was another concern, as well as the additional cost of travel and other logistics. Finally, we wanted to explore how well we all could evaluate learning in this unconventional educational environment. These elements are discussed in the final section. This study was based on a real case situation, not an experimental design. That means that the number of students taking part in the study was very few (three) and also not 'randomly' chosen, but based on their individual preferences and 'risk taking' in such an unconventional course situation. We are fully aware of this 'bias' in the study, but as a case situation we find it relevant to make some general reflections, put into our long teaching experience context, from the learning process we explored.

Results

General observations on the class organization and experiences

The course organization was built through a dialog between the instructor and the students. The Swedish instructor had extensive experience and had made substantial reflections on his own agronomy education. He had also developed an interdisciplinary perspective and theoretical framework for agriculture, and this was used as a platform for the planning process. During the meetings the instructor listened to the students' concerns with their present program's course design and implementation, and through questions and discussions tried to identify the key points in their frustration and key elements of the students' original interests in studying agronomy. In this process, the instructor and students uncovered the key elements of student motivation to pursue further education in agronomy. At this stage, the instructor had already interpreted the main frustration expressed by the students as: (1) frustration of not seeing a clear connection between the scale of farming and food systems (which was the focal interest for the students in entering the agronomy program) and the scale in focus in their first two semesters of the program (courses mainly in chemistry, molecular biology and soil chemistry); (2) the fixed and inflexible pedagogical teaching approach that enhanced a 'copy and paste' learning style instead of a 'learning for life' learning style; (3) the attitudes of many instructors in communicating with students as 'empty buckets to be filled with knowledge of the instructor', 'they (the instructors) don't seems to take us seriously in communication', said one student.

This method of designing a student-driven course, facilitated by dialog, was on the whole very successful and illustrated the potential for using such an approach for introducing more student initiative in course and program planning. But the students are not just turned loose, and we believe that a facilitator or instructor with personal experience and reflections, as well as knowledge in the area of the program, is crucial to the planning process.

An important experience in course design was the connection between trust in the students' capacity to take a major role in planning, in the instructor's ability to listen seriously to the students' needs, and in the high potential

students have for taking responsibility for their own learning. It was also important for the instructor to learn through the course evaluations, how much energy, power and effort it took for the students to take on such responsibility. There is obviously a great difference between student-driven and teacher-driven courses in the implementation of a full experiential learning program.

Reflections on the farm visits and analyses in Sweden

The choices of the two very different farming systems in Sweden turned out to be highly successful. By meeting two unique farming systems, the students quickly came to realize the importance of different motivations, goals and conditions that contribute to farming systems and practices. On the other hand, by limiting the number of cases to just two, it was possible to develop both a broader and deeper understanding of the farms, instead of a surface understanding of many different cases. It also helped students realize the importance of using different perspectives and 'glasses' in reading the context of a farming system. The influences from the human side of the system become very obvious early in the process. This could be an important learning objective if such a course could be used as the introductory activity for agronomy programs in the future.

The combination of reading text within a thematic area, discussion of this information with the two Swedish 'reference farmers' and with teachers and researchers at the university, was a unique opportunity to fit theory into local context. It was important to create a successful balance between students' time spent on individual and group processing, and how best to interact and efficiently use farmers' and teachers' time. The parallel reading and reflecting on a textbook on farming as a production system with environmental care[22] was also an essential element for learning about farming as an integrated activity.

Reflections on the visits to two villages in Viet Nam

It is obvious that this field trip provided many different and valuable inputs to the students' learning process, as described later. Students decided to undertake a field exercise in a totally different context from the first half-semester course, when important theoretical and methodological issues were processed in connection with Swedish farming systems. They needed to process and evaluate previous learning in order to determine what seems to be general and what is more contextual, and why. The great differences between Sweden and Viet Nam in climate, farming systems, social and economic situations, as well as culture and language, also contributed in a significant way to the students' learning, as expressed in their evaluations. It also put strong pressure on them to take initiative in the whole process, which was very demanding but also generated great confidence when they could realize good results from these efforts. Details of this multidimensional learning are provided in the individual student evaluations given later.

It is important to point out that this successful learning environment was only possible because of previous contact and solid cooperation already established between SLU, Hue University and the University of An Giang. To send students in their second year of university out to a field study in a different context requires appropriate contacts and a trusting academic environment as a starting point. We as teachers need to provide assurance to students that they can meet their learning goals to justify their investment of time and resources in the new program. Students need to place their trust in the cooperating institutions for orientation and support. To assure that collaboration, a long experience of institutional cooperation is probably needed. This reflection opens up the concept of establishing future organized international networks for this kind of student exchange in education.

Reports and evaluation of the field experiences

The students' learning process was evaluated and they were given regular feedback from teachers in reflective sessions, usually at the end of each week. Results of the students' field work were presented to an instructor in different formats, and often the feedback was given in oral form. Overall results of the first course were presented in a seminar organized by the student organization IAAS (International Association of Students in Agricultural and Related Sciences) in St. Petersburg on 22–29 October 2006. Results of the second course were presented in a report of the field study in An Gian[24] published by the SLU Center for Sustainable Agriculture.

St. Petersburg seminar. The seminar in St. Petersburg was part of a student union conference, with the theme 'agriculture and environmental issues in the modern world'. The students asked the organization if they could deliver an extra element in the conference by describing the course and their reflections on their learning process. The seminar was videotaped and presented to the course instructor back at the home campus, along with feedback and evaluation of the seminar event. The seminar was also a good environment for training in oral presentation skills.

Final report on Viet Nam. The field study at An Giang was processed into a full report. The course instructor and an external evaluator scrutinized and edited the report and gave feedback. This feedback was further processed by the students into a final version, which will be published in a report series at the department[24]. The report writing provided an additional learning process, in extraction of information from the field study, further reflection on the field experience, and also in organizing and communicating students' findings in the Viet Nam experiences.

Reflections on the Educational Experiences

The students and instructors responded briefly to three questions about the test pilot educational experience. Each of them provided comments on initial expectations for the independent study time, their reflections on the experience in the field and in working with the group, and their anticipated applications of the experience to future education and potential jobs. Here are the comments:

Reflections from Anna Nilsson (student)

The test pilot program excited mixed emotions, from really wanting to join this new experience to serious concerns about the unknown. Would it be relevant and would I have the discipline to do a very independent type of study? Much of my energy had been in the student union, so it was normal to be involved in my own future and take responsibility, and by then I had invested much time in planning the ideal 'course of our dreams'. I wanted to learn more about farming systems, connections between different sectors, and an overview as well as practical details. The opportunity to visit different farms, companies and researchers in Sweden seemed like a unique experience. And planning to go to Viet Nam provided a whole new window on agriculture and a different society, although I was not sure how well my previous knowledge would be applied to the completely new situation. The actual trip to Viet Nam and the experience at the university and in the field and villages are events that I still think about every day. It took a large amount of time and energy, but I learned so much that it was definitely worth it. The overall experience as a test pilot will follow me whatever I do in the future. It has helped me in planning, writing, communication and speaking, as well as in creating new possibilities for learning. It has also given me courage to work for change at the university and in society. With a friend, we plan to study the social and ecological impacts of GMO crops in South Africa, and I may become a journalist in science or an agronomist in rural development. The test pilot experience helped me in clarifying my own future goals for a career. I hope that this model can help change the conservative university education system, and that more power can be shared between students and teachers. With more students involved, there will be more growth in thinking, new attitudes and better connections with the real world. The process will create more self-confidence, belief in ourselves as people, less anger and more positive thoughts toward the system, and fewer students who drop out due to frustration. In general, this was a fantastic experience and I hope that more people have this opportunity.

Reflections from Sofia Palmer (student)

A very important learning experience for me was to realize the complexity in many situations and improve my ability to deal with that by *multi-perspective thinking*. For me the project introduced a totally new way of studying, which meant much more individual responsibilities and demands, but also a big challenge. Sometimes the situation during the project felt extremely exhaustive, but it definitely had a lot of good outcomes. The project gave me a much deeper engagement in my studies and much more motivation for future studies and career. First of all, it meant a lot to 'land up' in a more or less unknown situation—culture, society, language—and to try to deal with a new complexity and make an analysis from it. This kind of action-learning was a great experience for me. A very important and connected learning situation was how often we make wrong assumptions, because we are over hasty in applying our previous stereotypes about another country and culture. The experiences from the project gave me much practical knowledge through reading, writing and integrating all this with the field study, but also self-confidence and trust in my own abilities in a new situation. I am really impressed by our own group's performance, which is far better than my expectations before the project. After my studies, I want to work with environmental issues on a regional level connected to environmental communication and the use of natural resources. This insight partly came from the test pilot project, and I am sure the experiences from it will be useful for me in many different ways in the future. I am often reflecting on my experiences from the project and using these reflections in many different situations.

Reflections from Adam Roigart (student)

The course we took part in was something new to our university from two points of view. The overall thinking around the way of making a course as well as the subject was progressive. The normal way of dealing with agricultural subjects at our university is, as described above, to first be put in basic chemistry and calculus classes and from that point moving on to wider subjects. How wide they get, though, is a relative question. There are a great number of specialist educations, but none that has the ambition to create skilled generalists, until now. Before starting the course, I experienced a sort of intuitive feeling that this (current system) was wrong but had no means to put the feeling into words, due mostly to a lack of practical experience. Through field studies that were well within reach, relying on the knowledge gained through the seminars and the literature, we could experience *what it really was all about!* This included understanding, and appreciating, the role of the generalist as well as the specialist. I believe this point is important to make, since we were sometimes criticized for not wanting to learn things seriously. 'Taking matters seriously' meant dropping the overall picture in favor, for example, of deep studies of soil fertility (when the criticism came from the soil department). I assume someone from the department of animal husbandry would have another version! By having some practical experiences that clarify the role and the

importance of the generalist, one's self-image gains a lot. I am sure though that the kind of learning experience we had could be just as positive for someone wanting to specialize by helping them clarify their role in the whole context of agriculture.

Reflections from Lennart Salomonsson (instructor)

The idea for a test pilot project grew from our concerns as instructors that the present curriculum that includes a set of requirements for all students, starting with basic science such as chemistry in the first year, was not in tune with students' needs[8]. Without having a practical context into which new skills and knowledge could fit, students were often lost and not very motivated for education in our traditional classes in soils, crop science or other specialties. This was also my interpretation of what was the major part of the students' feeling of frustration with the curricula they opted for, when they first contacted our department. They seemed to be more interested in whole systems, and especially the interactions of the biological and economic dimensions with human society. Many students want to make a difference, but they are discouraged by not seeing how their studies could help them achieve that goal. By combining theories in systems ecology and farming systems with social science methods, students were much better prepared to look at systems both in Sweden and in Viet Nam. PRA and other practical tools used with farmers were found to be highly valuable, especially when students learn by actually doing this on farms. As a group, the students gradually took over more control of their learning agenda, and I became more of a facilitator and guide. We are sure that these students would have left crop science and perhaps the university if not given a different opportunity to grow. The final result is that all three of them have left their original programs; one started the landscape architecture program, one is starting a degree in rural development in the autumn semester of 2008, and one is now in environmental studies. All of them are however now highly motivated to seek careers in areas that are important to them. Each student has a clear plan of what to study, where they want to go, and how they will get there. Each feels that this opportunity to take charge of their education has resulted in personal growth, ability to work in teams and better understanding of whole systems. These should be among the goals of any educational program. I also reflected on the very high work load the students were putting themselves into, by taking such high responsibility in the planning of their curriculum and its implementation. As one of the students expressed in one of our evaluation session half a year after the course: 'In one way it was also comfortable to go back to conventionally planned courses, by the relief I felt to let all planning work to the teacher, and to have a period of 'lay back' for a while'. It was also important for me to understand the importance for the students in group reflection work to have a chance to change groups. All students in this course expressed that by the end of the full semester they had been working for such a long time in the same group constellation, that the importance in group processing to get other peoples' perspectives was less visible, as by now they could foresee many of their groupmates' comments.

Reflections from Charles Francis (instructor and evaluator)

The test pilot project provided one unique opportunity for Swedish students in the College of Agriculture to design and pursue their own ideas on how to accomplish their education. Based on reading the report from their study tour in Viet Nam, I am impressed with the depth of information and insight gained by the students in a short period in the field. To be sure, they were well prepared with a number of soft systems methods before leaving Sweden, and had some prior practice in the Swedish farming context. The help of people from the university in Viet Nam and from village leaders was essential in locating people to interview and providing students with local credibility in their task. Yet it is truly amazing what was accomplished in a short time. The production data they were able to access in Viet Nam are limited, of course, and the economics are necessarily shallow because it is difficult to obtain detailed information in such a short time and with so many people in the group—three students plus four or five interpreters. It would take a longer time and perhaps some fluency in Vietnamese language to achieve close confidence of the farmers and gain access to more detailed data on production and incomes. The environmental analysis is rather general, and relates primarily to pesticide use and comments about impacts of too much chemical residue in the ecosystem. The social elements are especially well developed, as the team focused in on labor use, family involvement, relationships with the commune leaders and women's groups and relatives, and national politics and their influence on local success in agriculture. This dimension is impressive, especially as conducted by crop science students with limited prior exposure to the methods needed to get this information. It appears to me that this type of educational experience can provide an unforgettable personal journey into another culture, and an essential part of the preparation of well-grounded professionals.

Reflections from a Group Session one year later

Sharing reflections in a group after a significant time has elapsed can bring out additional issues and conclusions, and can represent the consensus of all participants if a session is facilitated in a collegial way. As students, we were initially a bit skeptical if it would be possible to design an ideal course, with our limited experience, but we had in common a frustration with the currently structured curriculum. The student-designed course seemed to be an exciting opportunity. Each of us had different motivations, but saw this as a way to build on our previous experiences. There

was a strong belief among teachers and students in the concept of democracy in education[8], and we all considered it more important to focus on holistic views of agricultural systems rather than getting lost in the parts. The experience of meeting Swedish farmers was an opportunity for growth in our knowledge, and also to test the methods that can be used to gather information and analyze this to better understand the whole system. Applying these same methods and some complementary tools in Viet Nam provided additional challenges, working through interpreters in a totally different culture and environment, but it also gave a different type of chance for individual growth and building confidence. Moving back into more conventional classes was easier in some ways, since we did not have such a large responsibility for organization, yet it was discouraging to see the lack of motivation of others, some going to sleep, and some students not really interested in having an in-depth discussion. There was an obvious and large separation between teachers and students in conventional classes, compared to the co-learning environment in the test pilot program. As students we anticipate a large demand for future programs where students take more responsibility, where there is more interdisciplinary focus, and where there is more learning outside the university with clients in the real world. We conclude that students should participate more in the design of their learning, even though this is outside the comfort zone for both students and for instructors. The consensus is that we need new programs that incorporate all these ideas for change, and that it would be very difficult to introduce enough meaningful change into existing departments, curricula and courses. We recognize that this would take an incredible amount of resources and human energy, but the results for students and the university would be highly valuable as we create new learning environments and a learning organization.

As faculty in this review session, we were impressed with the level of excitement from students even one year after the field experience. They shared specific anecdotes, especially from the Viet Nam interviews, as if these had occurred yesterday. It was obvious that the experiential education as co-planned by them had a lasting effect on their motivation for continuing their studies, as well as creating a desire to continue to be more involved in planning and execution of educational activities. We have concern about the small number of students, and also the self-selection process that obviously limits the extrapolation of results to a larger student population. We concluded that only highly motivated, self-starting students who are willing to take responsibility and dedicate much additional time to the course would be prime candidates for this alternative type of education. It is a complement to conventional courses, rather than a complete substitute. In terms of faculty time dedicated to only three students, we recognize that this is less efficient than presenting lectures to a class of 50 or 200, at least as measured by conventional credit-hour criteria. On the other hand, the lecturing time was set to a minimum and much of this 'information delivering' was handled by students reading and group processing, and students' interviewing of people outside the university. There is a certain fixed cost to faculty who organize such a course, and the marginal additional time needed for 10–20 test pilot students would result in some efficiencies of scale in a course with expanded student numbers. Some of the fixed costs such as travel and support for a foreign experience such as the Viet Nam adventure would increase in proportion to student numbers. Alternatives that would be less expensive, yet provide experience in another culture, could be realized in nearby venues such as Estonia, Poland or western Russia. Finally, we recognize the difficulty in comparing the amount of learning from the test pilot experience with a semester in classes on campus, but our qualitative observations are that this was a highly impactful experience and one that would be difficult to duplicate in a local educational facility with formal classes. We also deal with students in conventional lecture classes, and this provides a standard for such comparison. There is no doubt about the importance of the field experience, and the level of motivation and dedication that was developed as a result of the test pilot opportunity.

Recommendations

As instructors, we can say that much of our previous experiences and reflective knowledge from curricula planning and course implementation at masters and graduate level was both confirmed, and even strengthened, in this test pilot course with undergraduate students in their third semester. We found this especially true in our reflections on 'just-in-time education'[7] and experiential learning[15,17,18], and the more dynamic perspectives on the cognitive process seen as a 'learning ladder'[24]. We observe the possibilities for students to achieve an integrative 'internal development', including an ethical and emotional maturation, by using an experiential approach in education.

This case study also showed us that it is possible to increase students' engagement and responsibility in their own learning process if instructors: (1) give the students space and facilitation to analyze and formulate their own inner driving force for learning; (2) take their perspectives, experiences and personal knowledge seriously in planning, feedback and valuation discussions; (3) give the students tools to work efficiently, but also space to develop in group project work and group reflections; and (4) take into account the energy needed for program planning, remember the challenges faced in implementing education, and also taking responsibility for the learning process. Much of this responsibility is passed on to the students, and we need to appreciate that serious students will find this a large but rewarding challenge. We also need to consider differences in learning styles, and that students will be involved in other courses that include different kinds of courses within their full programs.

This case study also shows that it is fully possible to let students in a very early stage of their undergraduate studies

take responsibility for rather advanced field work in the context of another country, but this assumes that good co-operation with colleagues in the partner universities is already in place. We observe that it is important for people in the host institution to have facilitation competence and abilities to guide the students in the new context, and give the students time for adapting and reflecting on the new context. This kind of advanced field study also demands a course structure that provides space for students to assume responsibilities for their own learning process and gives credit for the results. We observed the great impact that such a field project in another culture and context had on the students' self-confidence, maturity and self-insight, and how this led to choices in their future education and learning. Such advanced fieldwork opportunities take substantial resources for planning and implementation, but provide new qualities to the student's future learning process that are hard to overestimate.

Summary and Conclusions

Based on the levels of enthusiasm we achieved as students and instructors, the breadth of understanding generated about farming systems and the motivation to continue study in agriculture, this was a highly successful field exercise. As students, we gained invaluable experience in the international arena, leaving our comfort zone in the Nordic Region and traveling to the tropics to experience a completely different culture and series of farming systems. We had to adapt quickly to a new regime of food, language and translations, time change, and culture—typical of Southeast Asia and extremely different from Scandinavia. We used methods that had been tested in our own language and culture, and adapted these to a completely different context. It was essential to present ourselves well and quickly gain confidence with our interpreters and especially the people in the two villages. This seemed like a momentous task to accomplish in a short period of time, but we were able to meet all these challenges through close cooperation and with good humor. We stayed healthy. We adapted to the new situation, collected a large amount of information, took countless photos, and assembled a report that makes us proud. We are inspired to share this experience with others through publications and presentations.

This report should serve as a model for other student groups to emulate as they seek innovative ways to pursue an independent education. As instructors, our mission should be to provide some guidelines for design of a learning experience, and some checkpoints as students navigate themselves through the learning landscape. In a conventional curriculum made up of courses on campus, tested over decades and found to help students achieve certain learning goals, this path through the landscape is clear. What we are learning is that not all students are motivated by this traditional path, not all people learn in the same ways, and some seek new routes that will provide them with a broader perspective about what farming and food systems include. They want to be able to deal with complexity and uncertainty, and to deal with the multiplicity of factors that will be important in food systems in the future. This student-designed semester in Sweden and in Viet Nam has definitely provided such an experience for the three Swedish test pilots. With their help, we hope to improve the learning environment and provide more opportunities for growth in potential for independent thinking, setting personal and group priorities, and thus be better prepared for professional contributions in the future. The test pilot experience is one large step in that direction.

Finally, as instructors we have reflected on the importance of the teacher's attitudes in meeting and working with students. To face the student with trust, true interest in their individual goals, and taking their own experiences and knowledge seriously, we recognize these as key elements for creating a productive and trusting co-learning landscape. We make it clear from the start that all individuals in the learning group, students as well as teachers, will explore in their own ways. This demonstrates trust in dynamic self-organizing processes, where you have confidence that emergent properties will result if the process provides space to invite new, unpredictable events to happen, and to let them be tested and evaluated in each context. It becomes obvious to us that the central issue is more about trust and less about control.

From two experienced teachers with many years of practical teaching and curriculum development, implementation and reflections, and as fathers of our own adult children, we find great wisdom in a quote from Kahlil Gibran:

> Your children are not your children.
> They are the sons and daughters of Life's longing for itself.
> They come through you but not from you,
> And though they are with you yet they belong not to you.
> You may give them your love but not your thoughts,
> For they have their own thoughts.
> You may house their bodies but not their souls,
> For their souls dwell in the house of tomorrow,
> which you cannot visit, not even in your dreams.
> You may strive to be like them,
> but seek not to make them like you.
> For life goes not backward
> nor tarries with yesterday.
>
> [Kahlil Gibran (1883–1931, http://www.leb.net/mira/) On Children]

References

1 Odum, H.T. 1996. Scales of ecological engineering. Ecological Engineering 6:7–19.

2 National Research Council. 2003. Frontiers in Agricultural Research: Food, Health, Environment, and Communities. National Academy of Science, Washington, DC.

3 Altieri, M.A. 1987. Agroecology: The Scientific Basis of Alternative Agriculture. Westview Press, Boulder, CO.
4 Gliessman, S.R. 1998. Agroecology: Ecological Processes in Sustainable Agriculture. Ann Arbor Press, Chelsea, MI.
5 Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R.R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., and Poincelot, R. 2002. Agroecology: the ecology of food systems. Journal of Sustainable Agriculture 22(3):99–118.
6 Daily, G.R. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.
7 Lieblein, G., Østergaard, E., and Francis, C. 2004. Becoming an agroecologist through action education. International Journal of Agricultural Sustainability 2(3):147–153.
8 Salomonsson, L., Francis, C., Lieblein, G., and Furugren, B. 2005. Just-in-time education. NACTA Journal 49(4):5–13.
9 Dewey, J. 1942. Democracy and Education. Macmillan Publishers, New York.
10 Quinn, D. 1992. Ishmael. Bantam/Turner, New York.
11 Mezirow, J. (ed.) 2000. Learning as Transformation: Critical Perspectives On a Theory in Progress. Jossey-Bass Publications, San Francisco, CA.
12 McGill, I. and Beaty, L. 2001. Action Learning. Kogan Page Publications, London.
13 Reason, P. and Bradbury, H. (eds) 2001. Handbook of Action Research. Sage Publications, London.
14 Revans, R. 1998. ABC of Action Learning. Lemos and Crane Publishers, London.
15 Bawden, R.J., Packham, R., Macadam, R., and McKenzie, B. 2000. Back to the future: reflections from Hawkesbury. In M. Cerf, D. Gibbon, B. Hubert, R. Ison, J. Jiggins, M. Paine, J. Proost, and N. Röling (eds). Cow Up a Tree: Knowing and Learning for Change in Agriculture. – Case Studies from Industrialized Countries. INRA, Paris. p. 397–410.
16 Wiedenhoeft, M., Simmons, S., Salvador, R., McAndrews, G., Francis, C., King, J., and Hole, D. 2003. Agroecosystems analysis from the grass roots: a multidimensional experiential learning course. Journal of Natural Resources and Life Science Education 32:73–79.
17 Jordan, N., Andow, D., and Mercer, K. 2005. Ecology of agricultural systems: a service-learning course in agroecology. Journal of Natural Resources and Life Science Education 34:83–89.
18 Sriskandarajah, N., Francis, C., Salomonsson, L., Kahiluoto, H., Lieblein, G., Breland, T.A., Geber, U., and Helenius, J. 2006. Education and training in ecological agriculture: Nordic Region and U.S.A. In P. Kristiansen and A. Taji (eds). *Organic Agriculture – A Global Perspective*. CSIRO Publishing, Collingwood, Victoria, Australia.
19 Østergaard, E., Lieblein, G., and Francis, C. 2008. Student conversion to autonomous learners: a case study from agroecology. NACTA Journal (in review).
20 Lieblein, G., Francis, C.A., Salomonsson, L., and Sriskandarajah, N. 1999. Ecological agriculture research: increasing competence through PhD courses. Journal of Agricultural Education Extension 6(1):31–46.
21 Lieblein, G., Moulton, M., Sriskandarajah, N., Christensen, D., Waalen, W., Breland, T.A., Francis, C., Salomonsson, L., and Langer, V. 2005. A Nordic net-based course in agroecology – integrating student learning and teacher collaboration. European Journal of Open and Distance Learning, 1. Available at web site http://www.eurodl.org/materials/contrib/2005/Lieblein.htm
22 Källander, I. 2005. Ekologiskt lantbruk, odling och djurhållning [Organic farming, crop and animal husbandry] (in Swedish). Natur och Kultur, Järfälla, Sweden.
23 FAO. Overview of Participatory Rural Appraisal (PRA): http://www.fao.org/participation/english_web_new/content_en/linked_Pages/PRA_overview.htm; and Farming Systems Diagram: http://www.fao.org/Participation/ft_more.jsp?ID=3662
24 Nilsson, A., Palmer, S., and Roigert, A. 2008. Experiential learning in agroecology – report from a PRA study in Vietnam. Report Series from Department of Urban and Rural Development, Swedish University of Agricultural Sciences, Uppsala, Sweden (in review).
25 Lieblein, G., Breland, T.A., Ostergaard, E., Salomonsson, L., and Francis, C. 2007. Educational perspectives in agroecology: steps on a dual learning ladder toward responsible action. NACTA Journal 51(1):37–44.

Renewable Agriculture and Food Systems: 24(1); 60–71 doi:10.1017/S1742170508002421

Barriers to adoption of sustainable agriculture practices: Change agent perspectives

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Accepted 22 August 2008; First published online 8 December 2008 **Research Paper**

Abstract

Conventional agriculture systems of production often lead to environmental degradation, economic problems and even social conflict. The efficacy of agriculture systems conducive to the economic, environmental and social sustainability of farming operations has been demonstrated, yet the adoption of sustainable agricultural practices is not widespread. This qualitative study is based on a web-based survey instrument designed to elicit the barriers to adoption of sustainable agriculture practices (SAP) perceived by a positional and network sample of 269 change agents working with farmers in the US South. The analysis examines the general proposition that reluctance to change to SAP is an overused rationale of change agents that tends to mask real barriers that we endeavor to elicit in the survey. It was found that despite having support from technical assistance providers, farmers are rarely adopting SAP. Change agents often are not well prepared to attend to farmers' needs regarding SAP, particularly the needs of specific farming situations. Thus, farmers often struggle to obtain accurate information about the benefits of SAP. Government support programs often fail to encourage adoption due to lack of funding, inappropriate design and ineffective targeting of incentives. Reluctance to change is frequently mentioned by change agents, but more as a way of blaming farmers for nonadoption than explaining the often tangible reasons for their behaviors. Social barriers, land tenure, infrastructure and incompatibility are other significant impediments to adoption. Strategies such as improved management of the existing information, careful design of economic support programs and extension efforts addressed to change agents themselves could help overcome some of the barriers identified by change agents.

Key words: sustainable agriculture practices, barriers, adoption, change agents

Introduction

Despite the attractive alternatives that sustainable agriculture represents for many farmers, widespread adoption of sustainable agriculture practices (SAP) has not occurred[1–3]. Conservation tillage is one of the most commonly used sustainable practices in the USA. However, its adoption has been slow, and remains low[1,2]. Integrated pest management (IPM) practices were adopted by approximately 2% of the farmers in the year 1994, coordinators of the IPM program report[2]. Similarly, a 2001 national survey found that biological controls were in use on 3% of crop acres[1].

Little is known about the general state of adoption of sustainable practices at the national and regional levels. The 2002 census of agriculture does not include information about sustainable agriculture practices. Thus, the National Agricultural Statistics Service (USDA-NASS) intends to include information about sustainable agriculture in the 2008 agriculture census[4]. In the meantime, institutions that advance sustainable agriculture, such as SARE, may encounter many barriers to making informed decisions about their plans and strategies.

Traditional adoption theories underplay the fact that there are often sound reasons why producers are unable to adopt SAP[5,6]. Several studies have found that nonadoption of SAP is a rational decision under certain circumstances[5,7–9]. Consequently, a focus on factors constraining adoption and how to overcome them can be fruitful[3,5,7,9,10].

Several analyses of constraints to adoption of SAP in the USA are available[7,11–15]. However, little is known specifically about the spread of SAP in the southern United States, a region with droughty summers, intense rainfall events, heavy insect and disease pressures, and problematic

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soils. Previous research identifies various barriers to adoption of SAP, but none has focused specifically on the South. The specific objectives of this research are: to identify change agent views about barriers to adoption of SAP; and to suggest strategies for overcoming barriers to wider use of SAP.

Sustainable Agriculture and SAP

Most proponents of the concept will agree that sustainable agriculture is not a defined set of agricultural practices, but rather a utopian and dynamic condition, a long-term goal[16,17]. Although sustainable agriculture does not refer to a standard set of agricultural practices, there are certain methods or practices that enhance sustainability[2]. Such methods are regarded in this research as SAP. Some methods commonly mentioned in the literature are: crop rotation, cover crops, no-till and low-till farming, soil conservation, diversity, nutrient management, integrated pest management, rotational grazing, water quality, wetlands, agroforestry and alternative marketing[2,18]. Caswell et al.[1] examine a broad measure of adoption of *any* soil conservation practice on highly erodible land in a large national farm survey dataset, finding that over half of the highly erodible cropland acres were under some kind of soil conservation practice. Soil testing is the most fundamental SAP. A 2008 US national survey of nearly 2000 'top farmers' indicates that about half conducted soil tests according to state recommendations. Economic concerns and time were primary obstacles to soil testing. Twenty-four percent of corn growers, 23% of soybean growers and 23% of wheat growers cited test costs as a reason why they do not do soil tests.[40] It seems that a large portion of the nation's land is not treated with the most basic SAP.

Barriers to Adoption of Sustainable Practices

Previous researchers identified factors that impede widespread adoption of SAP[1,5,7,11,12]. The generation and spread of information, economic limits, social factors, farmers' characteristics, attributes of sustainable practices, and infrastructure conditions are previously identified barriers to adoption.

Barriers related to the supply of information are: rapidly evolving knowledge and information needs, lack of available information for farmers, and change agents' lack of information and knowledge[11,12]. The complexity of many SAP[7,19] creates a need for learning and better understanding of cropping systems, machinery and chemical tools that in turn impede adoption[5,11]. Some authors report that the lack of available, reliable or locally relevant information is another obstacle to adoption[7,11,20,21]. Inadequate information clarifying the economics of adopting, the technical details of implementation, and the likely production impacts of new sustainable practices are other barriers to adoption[7,11,13,22].

Lack of access to technical information in locally relevant, site-specific SAP is sometimes cited as an institutional failure[22,23]. Some authors relate this problem to inadequate knowledge about SAP available to change agents from traditional information sources[7,13,24]. Some authors decry change agents' lack of receptiveness or attentiveness to research findings from sources other than university research stations[24]. Paulson[14] concluded that change agent training often fails to stimulate them to reflect on their own beliefs, values and previous knowledge, which in turn reduces the effectiveness of such training. When information is available through applied publications, change agents often are unaware of its existence[13].

Economic factors

Economic factors are frequently mentioned in the literature as barriers to adoption of SAP by farmers and also by change agents. Some of these factors are the cost of materials and equipment, the uncertainty of profitability or increased risk, loss of productivity, labor supply, at-risk economic situations, and farm program policies.

Whether perceived or real, increased risk is often regarded as a barrier to adoption[7,11,13,20,23,35]. Some authors identify increased risk to yields during transition and implementation of SAP, especially when new equipment is required[7,8] or when the mix of inputs changes[27]. Wandel and Smithers[8] explain how the use of conservation tillage was incompatible with the farming systems of livestock that tended to use inverse plowing for manure incorporation.

Another barrier is the perception that SAP may reduce yields, though it is an empirical question whether a particular farm may have in fact greater profits from reduced costs associated with SAP[5,8,23]. Caswell et al.[1] analyze the claim that adoption of SAP will result in a decrease in pesticide or fertilizer use, finding little reduction in chemical loadings but no yield decreases (and some increases) in the five case adopter farms they examined.

Although it has been demonstrated that sustainable practices are as economically viable as conventional practices, profitability of sustainable practices is a concern among farmers and even change agents[2,9]. When sustainable practices are perceived as increasing the demand for labor, farmers might see this as disadvantageous because labor is often a scarce or expensive factor of production. They know the limits on their own time and energy and might be unable to provide the additional labor themselves. Additional labor costs may affect profitability. Farmers can also have serious concerns about whether the necessary labor will be available to hire when needed and at what cost[7,15,23,28]. In addition, farmers' poor economic situation has been identified as a barrier to adoption of sustainable practices[11,29]. Agunga[24] explains that technologies requiring considerable economic investment, such as conservation

tillage, are considered to be not worth adopting in small operations[8]. In the USA, the transition period can be perceived as risky by farmers due to an economic environment that generally favors conventional agriculture[30].

Farmers are on a technological treadmill where they must adopt yield and efficiency measures to stay competitive in a context of falling commodity prices. The same price pressures inhibit adoption of sustainable approaches having largely societal benefits[11].

Incompatibility with physical setting is another barrier to adoption explained in previous studies[7,31]. For instance, organic practices in Iceland are incompatible with the physical environment. The cool climate in Iceland makes the growing of nitrogen-fixing legumes difficult, which would otherwise help provide nitrogen-avoiding artificial fertilizers[31].

There are characteristics of sustainable practices themselves that have been identified as barriers to adoption. For example, complexity of SAP may be greater because they place more reliance on information and timing of activity to substitute for material or mechanical interventions[5,7,8]. In addition, difficulties in triability (reflecting the ability to experiment with practices on a partial basis), low observability of results, long time lag between treatment and effect, and the borderless nature of environmental problems have been cited as barriers[5,32].

Societal policies have been cited as an important factor that can constrain a farmer's decision to adopt SAP[2,3,22,29,30]. United States commodity price and income support programs have acted as barriers to widespread adoption of sustainable agriculture by encouraging producers to continue farming conventionally[14,23,25,30]. Moreover, the disparity between the amount of agricultural subsidies going to large farms and small farms often encourages recipients to retain conventional approaches[2].

Farmer characteristics

In addition to information and economic factors, there are other factors identified by previous studies to constrain adoption. Personal characteristics such as age, attitudes and beliefs are mentioned as barriers to adoption of SAP[7,8,33]. For example an attitude frequently identified as a barrier is the 'resistance to change'[8,33]. The belief that conventional systems give higher yields was identified as the biggest barrier to adoption of conservation tillage by Canadian farmers[8].

Land tenure

Ownership and use arrangements act as barriers to adoption in the USA[13,23]. Bell et al.[13] describe the implications of property rights issues for adoption of sustainable practices among farmers in Iowa. They found that the majority of leasing agreements were 1 year term and cash rent, which were antagonistic to adoption of sustainable practices.

Social infrastructure

The supporting context of neighbors, kin and peer farmers shapes a farming subculture or farming style and its associated norms about acceptable agricultural practices. Environmental practices are often new in such subcultures and farmers may be likely to implement such new approaches. In other words, adoption decisions are often based on imprecise factors such as 'what is considered to be socially and culturally acceptable by members of [potential adopters'] social group'[24,34]. As one change agent explained, 'Two drivers determine whether a farmer will adopt a new technology: if he thinks it's profitable and if his peers accept it'[5,35].

In the USA, infrastructural issues have been identified as a constraint to adoption of sustainable practices. Nowak[7] suggested that farmers were unable to adopt residue management systems due to unavailability and inaccessibility of supporting resources. Few farmers adopted these systems without significant support from local equipment and agrochemical dealers, USDA technical assistance, credit sources and other components of the surrounding agricultural infrastructure.

A lack of marketing infrastructure is a constraint to sustainable agriculture in the Southern United States[36]. Khanna et al.[36] found that drip irrigation did not reach widespread adoption until a support infrastructure was established and extension specialists, dealers, support staff and farmers understood its implementation and functioning.

Methods

Sample selection

The target population for this study was agricultural change agents in 13 Southern US states (Fig. 1). A combination of two purposive, nonprobability sampling methods was used to identify respondents: expert or positional sampling and snowball sampling. Expert sampling was used to obtain the views of people who have specific expertise by contacting individuals holding positions with responsibilities related to the substantive issue, sustainable agricultural practices[37]. Snowball sampling, asking respondents to refer other potential study participants, was used to augment the positional approach because there was no clear sampling frame and population was difficult to reach[38].

E-mail addresses for agricultural professionals were obtained from the websites of Land Grant Universities Systems, USDA, NRCS, American Society of Farm Managers and Rural Appraisers, Certified Crop Advisers of the American Society of Agronomy, and private consultants from commercial companies or other consultant networks (Georgia Association of Professional Agricultural Consultants, DuPont, Monsanto, Agrodist). Additionally, one list of 28 change agents that have been working with sustainable agriculture was obtained from Southern Sustainable Agriculture Working Group. Another list of 29

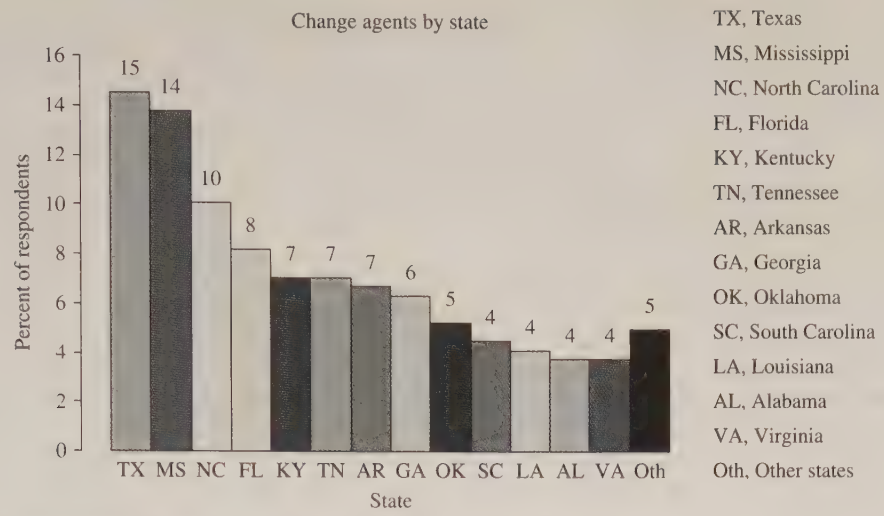

Figure 1. Number of Internet survey participants by state—2004.

SSARE state and area coordinators who could forward the survey to change agents was also included. A final list of 1292 valid e-mail addresses of agricultural professionals was contacted.

Data collection

A semi-structured questionnaire instrument was designed and distributed through e-mail. A set of 12 open-ended questions were utilized to capture respondents' verbatim opinions. These were combined with a set of 14 closed-ended questions that were intended to get a general description of tendencies regarding adoption of sustainable practices, the respondent's demographic description and background.

Respondents were contacted initially with a message explaining the objectives of the project, encouraging them to participate. A subsequent e-mail provided a URL address and instructions for participating in the study. Within a month, three additional follow-up e-mails were sent. Respondents were encouraged to forward the URL to other knowledgeable individuals with interest and expertise in sustainable agriculture. A final sample of 269 respondents completed the change agent survey.

Data analysis

Responses to the open-ended questions were separated in individual files containing the verbatim responses to each item. Each file was stored with a distinctive name and imported to perform analysis with ATLAS.ti software for qualitative data analysis. [ATLAS.ti stands for 'Archiv fuer Technik, Lebenswelt und Alltagssprache.' Translated, 'Archive for Technology, the Life World and Everyday Language.' The extension 'ti' (pronounced TEE EYE) stands for text interpretation. Project ATLAS (1989–1992) of Technical University of Berlin was the origin of the software's first prototype.] Cross case analysis of patterns among data was performed utilizing a variable-oriented strategy. Information for each respondent's answer was coded or classified in individual pieces of data (themes). A name or code was assigned to each coded content item[38].

Patterns were identified utilizing frequencies of each code and category. ATLAS.ti was used to obtain frequencies for each code. Frequencies of codes included in a cluster or category were added to find a frequency for that category. Thematic categories or clusters of verbatim comments were organized from most frequent to least frequent. Codes in each category were organized in the same way. This helped us to establish a hierarchy of importance among categories or themes. In summarizing the findings, *verbatim phrases or expressions from survey participants* were retained as much as possible and are reported in italics. Interpretation was kept to a minimum so that at a more refined level of analysis original expressions can be re-examined[39]. The analysis examines the general proposition that reluctance to change to SAP is an overused rationale of change agents that tends to mask real barriers that we endeavor to elicit in the survey.

Of the 269 responding change agents, 94% are male and 6% are female. Their ages ranged from 23 to 77 years, with an average of 48.5 years. Change agents were asked to classify themselves. The self-reports included professionals from agribusiness (37%), extension agents (24%), USDA-NRCS representatives (12%), nongovernmental organizations (9%), or other (17%). The participants were evenly distributed among the private and public sectors. Half the respondents were also farmers.

Results

Sustainable practice availability and adoption

Four questions measured change agent involvement in sustainable agriculture and perceived availability of sustainable practice information. Table 1 suggests that 43% of respondents are very much involved in supporting

Table 1. Perceived rate of adoption of sustainable practices (regional change agents, 2004).

Questions	Percent				
	Great extent	Somewhat	Slightly	Not	Don't know
Rate the extent of your involvement in supporting the adoption of sustainable agriculture practices ($N = 261$)	43	41	13	3	0
To what extent are clearly understandable and usable sustainable agricultural practices available to farmers to adopt in your state? ($N = 267$)	24	54	19	1	4
To what extent are farmers in your state adopting sustainable practices? ($N = 268$)	10	58	27	0.4	5
To what extent are farmers you work with adopting sustainable practices? ($N = 268$)	18	54	24	1	2

Table 2. Familiarity with selected sustainable agricultural practices (regional change agents, 2004).

Sustainable practice	Percent of respondents familiar with SAP ($N = 287$)		
	Not	Somewhat	Very
Soil testing	0.4	14	**84**
Crop rotation	0.4	22	**76**
Conservation tillage	3	21	**75**
Keep soil covered all year	0.4	24	**74**
IPM—pesticides management	4	33	**62**
Cover crops and green manures	1	40	**57**
Diversification	4	43	**52**
IPM—cultural management	5	43	**51**
IPM—biological control	7	47	44
Fresh plant as green manure	10	47	42
Weed control (rotation, minimum weed seed)	11	45	42

adoption of SAP, and 41% report to be only somehow involved. About 10% think that adoption is occurring to a great extent in their state or among the farmers they work with (18%). Also, less than one-quarter of respondents think that usable and clearly understandable SAP are available to a great extent in their state. Most respondents think that adoption and availability of SAP are at most occurring only at low level.

Change agents were asked to rate their familiarity with a set of 25 sustainable agricultural practices. Table 2 shows the SAP with the highest rating (50% or more) of respondents who reported being very familiar with eight of the 25 SAP listed in the survey.

In addition to the list of 25 sustainable practices presented to change agents in the survey, respondents had the opportunity to identify other practices that are currently used by farmers in the South. Change agents identified 118 additional practices. For purposes of analysis, the practices were then subdivided into 15 grouping categories. Table 3 lists each category and the frequency of practices under these.

Table 3. Sustainable soil and water practices used by farmers in the South (as reported by regional change agents, 2004).

Sustainable practice	Frequency	Percent of responses ($N = 67$)
Soil conservation	**37**	**57**
Nutrient management	13	19
Soil structure	11	16
Erosion control	7	10
Other soil conservation	6	9
Water conservation and management	**18**	**27**
Livestock	16	24
Pest control	15	22
Marketing	8	12
Economics	7	10
Crop production	6	6
Animal production	5	7
Waste management	4	6
Weed control	5	7
Organic production	2	3
Other	13	19

Table 4 shows the list of practices under each category. It is evident that change agents are aware of a variety of practices that are being used by farmers in the South. The majority of practices seem to be related to soil conservation. Water conservation, livestock and pest control are also issues that farmers are trying to include in their sustainable management. It is important to note that marketing and economic practices are also being included in sustainable management of farms in the South. The specific practices mentioned by respondents reveals the great variety of sustainable practices being used by farmers in the South of United States.

Barriers to adoption

Change agents were asked: What were the major obstacles or barriers that producers must overcome to adopt

Table 4. Categories of sustainable practices used by farmers in the Southern United States (as reported by regional change agents, 2004).

Category: Specific practices
Nutrient management: Precision farming remote sensing; GPS; controlled release fertilizers; legumes; split nitrogen applications; UAN solutions; natural fertilizers; homemade compost; mycorrhizal association
Soil structure: No-till; strip-till; spading; aerator; permanent beds; improved no-till
Erosion control: Riparian buffers; vegetative barriers; wind and contour strip-cropping; hay feeding in winter; cover cropping
Other soil conservation: Lime to optimum pH; intercropping; multicropping; restoration of marginal crop lands; crop to pasture land; flooding and growing rice
Water conservation: Canal bank vegetation; furrow damming; hoops structures; livestock exclusion; reservoirs building; storm water management; tail water recovery; water table control; irrigation water management; land leveling; multiple inlet rice irrigation; subsurface drip irrigation and fertigation; water-efficient center pivots
Livestock: Rotational grazing; agroforestry; seasonal dairying; suitable forages; silvopasture; alternative livestock
Pest control: Crop rotation; RoundUp Ready; filter strips; floating row covers; IPM—mating disruption; multispecies animal production; pesticides rotation; prescribed burns and good spray programs; Bt cotton; season extension; smart sprayers; botanical insecticides
Marketing: CSAs; direct marketing; farm stands; value-added products; farmers' markets
Economic: Cooperatives; financial analysis; local money systems; production for local markets; tax management heir property; record keeping; self-help funding; tax management heir property.
Crop production: Variety selection (native; locally adapted); cotton planted into wheat; alternative crops
Animal production: Pasture-based animal production; insecurity; range chickens
Waste management: Chicken waste application; mortality composting; methane digestion
Weed control: Drilled soybeans; flooding; herbicide rotation; narrow soybean row
Organic production: Organic crop; beef and dairy; organic certification
Other: Wildlife habitat management; buffer strips; cleaning out drainage; integrated crop/livestock; interning; on-farm plant breeding; on-farm seed production; stripper headers; transplants for direct-seed crops; farm to school programs; sod-based rotations; 'Best Management Practices' in forestry

sustainable agriculture practices? From the total responses to the survey, 78% of respondents answered this question. Their responses to this question are classified into eight categories listed in Table 5, which shows the frequencies and % for each variable from the total answers to this question.

Economic factors. Many economic factors constrain the adoption of sustainable practices. The most frequently mentioned barrier to adoption of sustainable agriculture practices is cost. This includes the '*initial cost*' of '*converting*' or '*changing practices*' including not only the '*cost of new equipment*', but also the costs of '*changing for one management style to another*', e.g. '*old tillage equipment has to be converted or sold to make way for NT*'. As another respondent stated, '*With commodity prices at the levels they are (basically unchanged in the last 50 years) and equipment prices at increasing levels every year, growers can't afford to change to strip-till or no-till. They can do some form of conservation tillage, but not to the extent they need to.*' Other respondents associated this problem with '*equipment prices at increasing levels every year*', which makes '*affordable technology*' unavailable.

The '*availability of alternative materials*' or '*organic materials*', '*lack of proper equipment*' and '*equipment*' were mentioned as problems for some farmers. For example, one respondent noted '*harvests equipment for narrow rows*' as a barrier to an SAP that uses dense plant populations to reduce the need for herbicides.

Respondents included as part of the initial cost the '*costs of the* [new] *system*', which are permanent or '*extra costs*', such as new inputs '*transportation costs* (e.g. '*organic materials*')'. One respondent called attention to the cost of sustainable compared to conventional practices, stating '*Synthetic products are cheaper in general unless you are using a by-product of your farm operation.*'

'*Most producers need to generate the maximum cash flow to keep the business running.*' Another wrote, '*So many growers are so squeezed financially that, even if their current financial situation under conventional farm* [management] *is terrible, they are afraid to make the jump into sustainable practices.*' One change agent explained that '*too many years of poor* [management] *places soil nutrient levels at a level that recovery does not fit into the cash flow*'. Another respondent suggested that some federal programs offer incentives to help farmers, but these are problematic; '*EQIP offers some incentives*, [but] *not enough.*' [The Environmental Quality Incentives Program (EQIP) was reauthorized in the Farm Security and Rural Investment Act of 2002 (Farm Bill) to provide a voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals. EQIP offers financial and technical help to assist eligible participants install or implement structural and management practices on eligible agricultural land.]

Sustainable producers sometime have problems '*getting more money for* [their] *products*'. This may be caused by

Table 5. Detailed summary of responses to the question, 'What were the major obstacles or barriers that producers must overcome to adopt sustainable agricultural practices?' (regional change agents, 2004).

Categories and content	Number	Percent of responses to question ($N = 210$)
Economics	**118**	**56**
Cost	29	14
Financial concerns	19	9
Uncertainty	15	7
Inadequate incentive programs/incentives	13	4
Profitability	10	5
Equipment change	8	4
Risk	8	4
Low commodity prices	7	3
Deferment of costs	7	3
Economics	2	1
Education and information	**111**	**53**
Lack of knowledge/education	40	19
Lack of information	17	8
Lack of institutional support of information sources	15	7
Change agents' beliefs about SAP	14	7
Need of information about effectiveness	11	5
Information management	6	3
Giant corporations	5	2
Lack of information about government programs	3	1
Resistance to change	**50**	**24**
Use of technology	48	23
Time incompatibility	12	6
Labor incompatibility	7	3
Lack of on-farm trials and demonstrations	7	3
Weeds/pests	5	2
Incompatible with management	5	2
Incompatibility	4	2
Incompatibility with operation size	4	2
Complexity	4	2
Social considerations	**33**	**16**
Change in beliefs	8	4
Perceptions of inefficacy of some SAP	8	4
Peer pressure to avoid SAP	7	3
Lack of farmer examples	6	3
Misleading perceptions	3	1
Conventional/sustainable opposition	1	0
Infrastructure	**19**	**9**
Inputs and equipment	10	5
Financial institutions	6	3
Market	2	1
Lack of processing options for small scale	1	0.5
Landlessness	**15**	**7**
Personal characteristics	**7**	**3**
Age	5	2
Apathy	2	1

'*bias of food retailers against small-scale producers and distributors*', or perhaps agricultural policies that are unfavorable to small producers. A respondent explained, '*Low commodity prices ... have placed some producers in that area of not being financially* [sound] *enough to adopt, or 'tool up' to more sustainable practices.* [Basically], *they are out of business but don't realize it yet.*'

Some respondents felt that adoption of SAP was moving slowly due to '*lack of some funds to motivate participation*'. More precisely, failure is a result of '*lack of governmental incentives for sustainable farming*'. A respondent affirms that there are government incentive programs, but '*insufficient government support for adoption and expansion of sustainable practices on working lands (the new Conservation Security Program was originally designed to address this, but was largely gutted by low budgets and highly restrictive enrollment criteria)*'. Another change agent mentioned that in '*cotton country, the barriers consist of government payments*'.

Some change agents think that government programs are ineffective or even detrimental because they are '*tailored for large farms*' or show '*bias towards large-scale producers in federal programs (EQIP)*'. Others may be discouraged from adopting SAP by '*Federal, State and WMD regulatory programs which require extensive permitting* [licensing] *and engineering studies to implement common practices*'.

Farmers have an '*increased risk of losses to insects, weeds, and pathogens*'. Thus, '*many farmers feel that the potential lost in income does not justify adopting more sustainable practice*'. Some respondents think that farmers' '[idea] *that sustainable growing cost*[s] *more*' is the barrier. Others mentioned that it is '*hard to see immediate benefits*' with sustainable agriculture because '*some of these practices provide benefits but only over long-term usage*'. Thus, it is important to '*prove that sustainable agriculture is profitable TODAY*' in order to facilitate decisions to adopt SAP.

Education and information. Farmers' lack of knowledge or education '*concerning sustainable agricultural practices*' was frequently expressed as a barrier. As was stated, '*not being familiar with practices*' or '*unfamiliarity with a lot of practices*' is constraining potential adopters due the uncertainty of changing to something unknown. Thus, the need for '*learning*' about sustainable practices was often mentioned as an important barrier. One change agent notes, '*Many lack an understanding of how the practice will benefit them in the long term*'; they are '*uninformed as to the benefits to sustainable agricultural practices to their land, communities and income*'. They need '*knowledge that the new system will pay*'.

Change agents perceive a '*lack of good sound information*' about SAP, a '*lack of good economic information on use of practices*' and a lack of '*knowledge and understanding of long-term benefits*' of sustainable practices. A respondent felt that '*there is no local research showing dollars and cents savings from certain practices*'. In

addition, a general lack of sustainable alternatives was reported. Thus, it was suggested that '*practices that are practical and effective must be developed and advocated*'.

Many stated that there is an '*educational problem*' among farmers and suggested that they need '*more education*' in general and in specific '*on the sustainable agricultural practices concept in stewardship of the resource and how they are beneficial to income of the farm*'. One respondent even stated that '*sustainable farming is a highly skilled profession! There is simply SO much to learn, and you can only learn some of it in textbooks.*' Farmers' lack of education may lead to their '*lack of ability to adopt and successfully use improved technology*'.

Inadequate management of information. Other respondents think poor connections between producers and SAP information sources is a central problem. One wrote, '*I could have said "lack of information" or "need for more information" or even "insufficient awareness of, and support for sustainable agriculture in extension services". However, there has been major improvement in each of these areas over the past few years*—[such as] *more and more sustainable ag research and outreach, vital information services such as ATTRA ... big information-related barrier is how to access and assimilate the growing mass of information, sort the good info from the less-substantiated and the downright bogus, and most challenging, how to apply it to one's specific farm!*'

Farmers often have trouble finding the information they need for their farm. '*Most practices are good in paper, workable in research settings* [but] *difficult to apply on a large scale.*' The implementation is not only difficult when it is done at large scale but when there is variability within farms. One said, '*Some of my farmers farm different types of soil, requiring different systems ... too much confusion.*' In consequence, it was suggested that there is a '*need to develop better and more user-friendly methods or approaches to sorting out what practices would be truly sustainable and economically viable for a specific farm*'.

Lack of on-farm trials and demonstrations. Change agents report that farmers '*lack good tests of what practices will work best on their farm*'. Another change agent explains that there is a need for '*application by local Universities to demonstrate feasibility*' and '*intangible benefits such as improving soil, reducing weed growth and other aspects that are hard to economically quantify*'. On-farm trials and demonstrations can be means to solve this barrier to the adoption of SAP.

Lack of institutional support. The agricultural knowledge and information system may be failing sustainable agriculture. As explained by a respondent, '*Local governments* [are] *more interested in revenues to induce manufacturing.*' Another felt that '*lack of support in traditional ag structure—Farm Bureau, Dept. of Ag, extension*' is an important barrier to production and dissemination of information.

Moreover, some believe these organizations do not support SAP. There is a lack of '*acceptance, support, and promotion by the extension service and USDA agencies line employees*'. The '*county extension agents (home and agriculture) and vocational agriculture teachers, plus university extension professors who are* [farmers'] *sources of information, who:* 1) *believe that sustainable means subsistence agriculture,* 2) *do not believe in it and openly do not support or detest it, and* 3) *are not willing to change*'. Other reasons for the lack of institutional support are '*lack of full-time person*[nel] *devoted to sustainable agriculture in the university system*' and the '*lack of knowledge by extensionists and other Ag. Advisers*'.

Another respondent explained that the roots of the problem may be economic constraints in the universities: '*Land grant universities have sold out to chemical or pharmaceutical companies, so research and teaching do not focus on sustainable practices (unless of course the university can get some of the scarce grant money) ... So unless a farmer is willing and able to go beyond what he or she is offered by the usual information sources (Extension, chemical companies, Farm Bureau, etc.), there is almost no access to alternatives. It's getting better, but in most cases farmers have to find their own resources.*'

Change agent beliefs. Some change agents believe that reduced yields are associated with sustainable practices. This can be interpreted from a change agent's expression about barriers to adoption: '[farmers] *can't give up yield*'; or '*sustainable agricultural practices ... cuts maximum yields*'. Some explained that this reduction is caused by a '*loss of some crop land*'.

Influence of the private sector. Corporate influence on national agricultural policy is another barrier related to information generation and dissemination. This was even cited as '*possibly the most severe barrier of all in the long run*'. As one change agent explained, '*the concentration of food system economic power and control in the hands of a few giant corporations*' are barriers because '*these economic interests pull all kinds of strings to dissuade or even prevent growers from adopting truly sustainable systems—mostly through lobbying at governmental levels to limit the growth of pro-sustainable policy; to remove limits on GMO crops and livestock, and on corporate power over growers (contracts, markets); and to maximize global "free" trade (giving corporations even more control internationally)*'.

Resistance to change. Frequently mentioned barriers are: farmers' '*reluctance*' or resistance to change '*traditions*', '*old habits*', '*old ways of doing things*', referring to a '*mindset*' that limits involvement in sustainable practices. One respondent expressed, '*There is a mindset in many cotton farmers that leads them to monoculture even when they agree that it would pay to diversify.*'

Some respondents gave explanations for these attitudes. Some connect this type of farmer attitude to tradition. That is, the fact that '*often times a grower farms the way he farms because his daddy did it and his granddaddy before that*', so that their way of farming is a '*custom or cultural habit*' and the change then represents '*cultural shifts*'.

Second, resistance to change was also attributed to their '*thinking that their dads and granddads didn't necessarily farm in a sustainable fashion, so sustainable practices are not the best route to take, i.e. Dad and granddad raised excellent crops and did not practice sustainability very much at all*'. So farmers may see no need to change '*what works now*' and are reluctant to change to something new that they are unfamiliar with.

In a third instance, change agents consider the comfort associated with farmers' current management strategies as a cause of their resistance. Farmers '*are accustomed to having their cropping system wrapped in a nice package (jugs and bags) and readily available to apply today. This is habit forming and the habit will be hard to break.*'

Fourth, some management strategies have developed after many years of trial and error learning processes and therefore are difficult to change. As was explained by a respondent, '*Most producers are caught up in the old paradigm of using petroleum based fertilizers and pesticides to increase or maintain crop yields. They believe in that system. They trust that system. They often have such little faith in the sustainable practices that they dismiss them before they try them. Many producers do not even want to learn about sustainable agriculture. They feel an aversion to the name.*' Finally, farmers resist sustainable practices because they '*have to try new methods and many are not willing to make that change*'.

Age was also mentioned by some respondents as a barrier to adoption. The problem of '*overcoming the "that's the way we've always done it" mentality*' is not only about the young or middle-age farmers who are doing things as their predecessors did. It is also about '*the older traditional farmers*', that some change agents felt '*are not going to change*'. This was noted as an issue for younger and middle-age farmers because the '*older generation*' are the ones '*that still have control over the land*' in many cases.

Compatibility with existing practice. The fit with ongoing habit and pattern can be an obstacle to any new way of doing things. Time incompatibility refers to the time that practices require for implementation. Farmers may not have the labor or attention span to implement them successfully. As stated by a change agent, these practices are '*too time consuming*', because of the need of '*investing the time to learn different methods*' or '*to implement some practices*'. Farmers may also find labor incompatibilities as an issue to consider when thinking about changing to sustainable practices.

The incompatibility of practices with current systems was identified as a barrier. One change agent explained that for some farmers the '*new method ... doesn't fit well into their current practices*'. Incompatible management styles were mentioned as a barrier.

Incompatibility with operation size is another barrier because '*most producers are farming a greater number of acres than they used to be. Their time is strained trying to implement their normal operations.*' Large producers may find it difficult or more costly, as '*larger producers feel it costs more and will slow them down in the busy season*'.

Complexity. One barrier related to the lack of information is the complexity of sustainable practices. This refers to '*the highly complex and site-specific nature of sustainable and organic farming methodologies*'. A respondent explained that '*the variability of reaction to sustainable practices is a big problem. One soil or field may respond differently from another because of historical use, extent of previous topsoil loss, the existence of natural root restriction zones, etc. Tillage resolves some of this inherent variability, and makes more soils act alike, thereby simplifying management for farmers.*' One respondent asserted that '*the interactions between soils, crops, insects, weeds, micro-organisms and livestock are so complex that much is still unknown. As a result, a specific practice that works very well in one situation may not work in another.*'

Perceived efficacy of SAP. '*Fear of the unknown*' makes farmers ask, '*Will this different way of controlling weeds, insects, etc. really work?*', '*Will the practice work in my climate, in my soils, and with my management style?*' Moreover, with adoption of sustainable practices, '*Most often the producer fears that the new practice will not work and thus decrease their profit.*' According to one respondent, a '*widespread disbelief that these practices will work*' prevails among both change agents, and farmers. One change agent identified the '*efficacy of some practices compared to conventional measures*' as a barrier.

Moreover, the view of change agents that conventional practices are effective in achieving sustainability is hindering the adoption of sustainable practices. Other change agents felt that '*current production methods are keeping our producers financial sound (sustainable). Adopting some of the methods proposed by SSARE would reduce profits and make some operation un-sustainable.*' Another respondent felt that '*Profitability in my mind is the largest road block hindering sustainable agriculture practices.*'

In addition, the socially-created belief that the appearance of the field is an indicator of competence affects negatively farmer decisions to adopt sustainable practices. Farmers feel the '*need to have best looking fields*'. '*Farmers are prideful people who want other farmers to see weed free fields with row*[s] *that are completely weed free.*'

Other social barriers to adoption of sustainable practices are lack of farmer examples and peer pressure. It was explained that there are '*not enough examples for farmers to observe*' or even more precisely, the '*lack of good successful examples*'. Peer pressure is another constraint, which was even considered by a change agent to be a '*much bigger deterrent than most folks realize*'. Some '*believe that sustainable means subsistence agriculture*' or '*way out practices*'. Others hold perceptions that "*sustainable is organic and the idea that the organic folks are determined*

to take away the chemical options that traditional farmers have'. '*Producers' dislike avid sustainable ag proponents who often badmouth what the evil greedy or stupid farmers are doing to our environment.*'

Finance and infrastructure. Lenders do not seem prepared to support the transition to sustainable practices. This barrier refers to the fact that '*banks and insurance programs* [are] *not set up to accommodate the different practices involved in sustainable ag*'; '*lenders ... are not knowledgeable*' about sustainable practices.

Some mentioned a '*lack of proven market history for sustainable products*' that may affect the development of '*markets for new crops*' and a lack of '*established distribution networks for sustainable products*'. On the other hand, the '*bias of food retailers against small-scale producers and distributor*' may also limit the development of market alternatives for sustainable products.

Another aspect of infrastructure that is affecting sustainable producers is the lack of processing options. One respondent stated that there is a '*complete lack of facilities for small-scale poultry processing; limited facilities for temporary storage of horticulture crops (cooler space); lack of local canning, freezing, processing facilities that are available to the farmer or local processor*'.

Land tenure. Another frequently mentioned constraint on SAP adoption is '*absentee land ownership*'. A respondent remarked that '*landlord or tenant relationships control* [most] *of the acres*'. Producers who are '*farming leased land*' might be reluctant to adopt sustainable practices because usually '*landlords dictate what can be done with their land*'. The landlord '*may or may not allow*' such changes. Farmers may also be refrained by the only reason that he will '*worry about what the land owner will say*'. Moreover, one producer remarked that there is an increase of farmers with '*limited amount of land to farm*', a problem attributed to '*land utilization issues*' such as '*high land values and increases* [in] *land development*'.

Personal characteristics. Because of the farming history of old generations, some change agents think that age is a definite barrier to adoption. Older farmers are less likely to consider sustainable practices. In contrast, '*younger growers may be more interested*' in SAP because older farmers may be '*ready to retire*' and '*do not have the years to see some of the benefits*'. As mentioned before, older generations may discourage younger ones from using sustainable approaches often because they '*still have control over the land*'.

Another identified barrier is farmers' apathy toward the negative effects of conventional farming. A lack of understanding of sustainable farming systems may inhibit adoption, as explained by a respondent, '*They can't see that farming is a whole system, they can only see the bits and pieces.*' Others felt that farmers are unable to perceive negative effects of conventional farming and '*they require proof that bad practices (pesticides) are harming them and their land*'. A change agent noted that farmers' '*perceptions that changing practices may result in* [yield] *loss*' is a barrier to adoption of these practices.

Conclusions

Sustainable agriculture practices are not widely adopted in the Southern United States. The delivery of sustainable agriculture practices presents one central source of difficulty identified by respondents. The limited number of change agents highly involved in promoting sustainable practices, a limited number of change agents who are very familiar with some of the common sustainable agriculture practices, and the uneven availability of clearly understandable and usable approaches all inhibit the advance of sustainable practices in the region.

However, the demand for these practices is great, due to the great variety of them being used by farmers in the South. Soil and water conservation strategies are significant in a region of frequent intense rainfall events and thus receive more attention by farmers and agencies. Farmers are also using new practices to maintain financially sound operations, including marketing, financial management and credit strategies. In addition, farmers are using sustainable practices that are more specific to their operations (livestock, animal and crop productions). This indicates the need for more attention to specific production systems by research and extension agencies.

Economic and education/information issues are the most salient themes emerging from change agents' responses to the question about barriers to adoption in the South. Resistance to change and incompatibility of sustainable agriculture practices are impediments. Social and infrastructural issues are also influencing adoption of SAP. The most frequently mentioned economic factors preventing farms from adopting are cost and the financial situation of the farmers. Initial and transition costs are important barriers, as is uncertainty about these practices, against farmers' decision to adopt.

Among the barriers related to education and information, lack of knowledge and training is the most significant barrier identified by respondents. Lack of information and institutional support from traditional information sources are significant factors constraining adoption. The US Land Grant system, at least in the view of southern respondents, still has not fully embraced sustainable agriculture as a central path of development. Change agents' beliefs about sustainable agriculture practices were identified as an important barrier causing the lack of support for these practices.

The most frequently mentioned barrier to adoption is reluctance to change. However, this issue was not fully explained by many respondents. Some respondents viewed this resistance to change in terms of culture and traditions, the practicality of staying under a known, less complex and effective system (in the farmers' view), and in terms of the many costs associated with adoption.

Barriers related to the incompatibility and complexities of sustainable agriculture practices are considerable. The social context is a source of barriers to adoption; socially held beliefs and perceptions of change agents, peers and the other members of their community can negatively influence the decision to adopt. Some of these beliefs are tied to the lack of information and knowledge about sustainable agriculture and the traditional production paradigm. Barriers to adoption related to infrastructural conditions and land tenure in the South are also issues to consider.

Implications and Recommendations

Sustainable agriculture needs greater support from traditional information source agencies. This is limited by the lack of funding for sustainable agriculture that these institutions face. However, data from the present research support the idea that better administration of scarce resources could have an impact on the spread of adoption of sustainable practices. Adequate allocation of financial incentives and grant monies and constant evaluation of their impact can generate positive results.

Agencies need to be careful in choosing the allocation of economic resources. Targeting farmers and change agents who are truly interested in sustainability, who need the economic help and who can maximize the impact of such scarce resources can lead to a better impact of programs. Another approach, less costly than investing in research and dissemination of SAP, is promotion of farmer clubs and discussion groups focused on the issue. Grassroots associations defined by shared interests and common problems are key means for like-minded producers to support each other and share experience.

This type of approach served in other parts of the country as a very effective way to promote sustainable agriculture. In this way, extension agencies could serve as simple facilitators of communication and organization of such groups at the local level. At the regional, state and national levels, extension could help unite these local groups in their vision, objectives and shared interests or problems[40].

Additionally, improved management of the existing information should lead to relevant and available information for change agents and farmers. In turn, this should help overcome the many beliefs and uncertainties about sustainable agriculture and lead to widespread acceptance of the idea. Practices need to be designed and delivered under a bottom-up approach that allows for initial assessment of local needs. This can reduce unnecessary efforts and expenses.

Agencies should relinquish ideas that have been left behind by the traditional extension paradigm. The idea that farmers are to be blamed if adoption does not occur after information was provided needs to be abandoned. If farmers fall under such criticism, this study shows that the farmers' decision of nonadoption might be rational under the limitations of current conditions. Those committed to promoting sustainable agriculture need to examine how they can help producers overcome the more immediate material and technical barriers to the use of SAP.

It is clear that agencies need to address their efforts not only to farmers but to change agents, communities, and the general public as well. This can help reduce some of the beliefs and perceptions that are hindering adoption, and at the same time increase public support of the concept. Public support in the long run will help sustainable agriculture assert its role as contributing to food security and national security.

References

1 Caswell, M., Fuglie, K., Ingram, C., Jans, S., and Kascak, C. 2001. Adoption of Agricultural Production Practices: Lessons Learned from the US Department of Agriculture Area Studies Project. Agricultural Economic Report No. AER792. 116 pp. Available at Web site http://www.ers.usda.gov/publications/AboutPDF.htm (verified 10 July 2008).

2 Derpsch, R. 1998. Historical Review of No-tillage Cultivation of Crops. Available at Web site http://www.fao.org/ag/ags/agse/3ero/harare/partii/21Derp.htm (verified 20 September 2007).

3 Horrigan, L., Lawrence, R.S., and Walker, P. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives 110:445–456.

4 USDA-National Agriculture Statistics Service. 2005. NASS FY 2003 and Revised FY 2002 Annual Performance Plans. Available at Web site http://www.usda.gov/nass (verified 10 August 2007).

5 Vanclay, F. and Lawrence, G. 1994. Farmer rationality and the adoption of environmentally sound practices; a critic of the assumptions of traditional agricultural extension. The Journal of Agricultural Education and Extension 1:1–5. Available at Web site http://library.wur.nl/ejae/v1n1-5 html (verified 23 July 2007).

6 Hooks, G.M., Napier, T.L., and Carter, M.V. 1983. Correlates of adoption behaviors: the case of farm technologies. Rural Sociology 48(2):308–323.

7 Nowak, P. 1991. Farmer adoption of production technologies. In Crop Residue Management for Conservation. Proceedings of the Soil and Water Conservation Society National Conference, Lexington, KY, 8–9 August 1991, p. 31–41.

8 Wandel, J. and Smithers, J. 2000. Factors affecting the adoption of conservation tillage on clay soils in Southwestern Ontario, Canada. American Journal of Alternative Agriculture 15(4):181–188.

9 Roling, N.G. and Jiggins, J. 1994. Policy paradigm for sustainable farming. Journal of Agricultural Education and Extension 1(1):23–43. Available at Web site http://library.wur.nl/ejae/v1n1-5.html (verified 22 June 2005).

10 Cary, J.W., Webb, T., and Barr, N.F. 2001. The adoption of sustainable practices: some new insights. Land and Water Australia, Canberra. Available at Web site http://www.lwa.gov.au/downloads/final_reports/BRR19.pdf (verified 5 September 2005).

11 Norman, D., Janke, R., Freyenberger, S., Schurle, B., and Kok, H. 1997. Defining and implementing sustainable agriculture. Kansas Sustainable Agriculture Series 1:1–14.

12 Young, D.L. 1989. Policy barriers to sustainable agriculture. American Journal of Alternative Agriculture 4:135–143.
13 Bell, M.M., Carolan, M.S., Mayerfeld, D., and Exner, R. 2001. Professional development for the adoption of sustainable agriculture on rented land. Final Research Report. Department of Sociology, Iowa State University, Ames, IA.
14 Paulson, D.D. 1995. Minnesota extension agents' knowledge and views of alternative agriculture. American Journal of Alternative Agriculture 10(3):122–128.
15 Schneeberger, W., Darnhofer, I., and Eder, M. 2002. Barriers to the adoption of organic farming by cash-crop producers in Austria. American Journal of Alternative Agriculture 17(1):24–31.
16 Ikerd, J.E., Osburn, D., and Owsley, J.C. 1997. Some Missouri farmers' perspectives of sustainable agriculture. Department of Agriculture, Food and Natural Resources, University of Missouri, Columbia, MO. Available at Web site http://www.ssu.agri.missouri.edu/faculty/jikerd/papers/tsu-surv.htm (verified 15 April 2005).
17 Diver, S. 1996. Toward a sustainable agriculture. New Renaissance 6(2):19–21. Available at Web site http://www.ru.org/artagri.html (verified 28 May 2005).
18 Sustainable Agriculture Research and Education. 2003. Exploring sustainability in agriculture. Available at Web site http://www.sare.org/publications/explore/index.htm (verified 15 August 2005).
19 de Souza Filho, H.M. 1997. The Adoption of Sustainable Agricultural Technologies: A Case Study in the State of Espirito Santo, Brazil. Ashgate Publishing, Brookfield, VT.
20 Gamon, J., Harrold, N., and Creswell, J. 1994. Educational delivery methods to encourage adoption of sustainable practices. Journal of Agricultural Education 35(1):38–42.
21 Pannell, D.J. 1998. Social and economic challenge to the development of complex farming systems. Sustainability and Economics in Agriculture (SEA) Working Paper No. 97–02. University of Western Australia, WA, Nedlands, WA, Australia. Available at Web site http://www.crcsalinity.com.aunewsletter/SeaNews/spap972.htm (verified 21 September 2008).
22 Young, T. 2003. Adoption of sustainable agricultural technologies: economic and non-economic determinants. ESRC Global Environmental Change Programme. Available at Web site http://www.sussex.ac.uk/Units/gec/pubs/briefing/brief-21.htm (verified 1 May 2005).
23 Northwest Area Foundation. 2004. The Adoption of Sustainable Agriculture: Meeting the Challenge. Available at Web site http://www.nwaf.org/pubs/pubs_row_06.htm (verified 17 March 2007).
24 Agunga, R.A. 1995. What Ohio extension agents say about sustainable agriculture. Journal of Sustainable Agriculture 5(3):169–187.
25 Soil and Water Conservation Society. 1995. Sustainable agriculture. Available at Web site http://www.swcs.org/t_publicaffairs_sustainable.htm (verified 13 June 2004).
26 Pretty, J. 2001. Farmer-based agroecological technology. International Food Policy Research Institute. Washington, DC. Available at Web site www.ifpri.org/2020/focus/focus07/focus07_02.htm (verified 26 April 2005).
27 Rawson, J.M. 1995. Sustainable agriculture. CRS Report for Congress 95–1062. National Library for the Environment. Available at Web site http://www.ncseonline.org (verified 17 March 2004).
28 Antle, J.M. and Diagana, B. 2003. Creating incentives for the adoption of sustainable agriculture practices: the role of carbon sequestration. American Journal of Agricultural Economics 85(5):1178–1184.
29 Arellanes, P. and Lee, D.R. 2003. The determinants of adoption of sustainable agriculture technologies: evidence from the hillsides of Honduras. The 25th International Conference of Agricultural Economists, 11–16 August 2003, Durban, South Africa.
30 Reed, M. 2004. More than just fashionable foods: the importance of social sciences in organic research. Organic-Research, March 2004. p. 1N–5N. Available at Web site http://www.Organic-Research.com (verified 17 March 2004).
31 Marra, M., Pannell, D.J., and Ghadim, A.A. 2004. The economics of risk, uncertainty, and learning in the adoption of new agricultural technologies: where are we on the learning curve? SEA Working Paper No. 01–10. North Carolina State University, Raleigh, NC.
32 Vanclay, F. and Lawrence, G. 1995. Agricultural extension as social welfare. Rural Society 5(1):20–33. Available at Web site http://www.csu.edu.au/research/crsr/ruralsoc/v5n1p20.htm (verified 15 March 2005).
33 Dyrmundsson, O.R. 2000. Organic agriculture under northern conditions: Iceland. The 13th International Scientific Conference, 28–31 August 2000, Basel, Switzerland. Available at Web site http://www.organic-research.com/research/papers/iceland.asp (verified 2 April 2004).
34 Texas Environmental Profiles. 2004. Sustainable Agriculture. Available at Web site http://www.texasep.org/html/lnd/lnd_2agr_susdev.html (verified 17 March 2004).
35 Bearenklau, K. 2005. Toward and understanding of technology adoption: risk, learning, and neighborhood effects. Land Economics 81(1):1–19.
36 Khanna, M., Millock, K., and Zilberman, D. 1999. Sustainability, technology and incentives. In F. Casey, A. Schmitz, S. Swinton, and D. Zilberman (eds). Flexible Incentives for the Adoption of Environmental Technologies in Agriculture. Kluwer Academic, Dordrecht, The Netherlands. p. 97–118.
37 Trochim, W.M.K. 2001. The Research Methods Knowledge Base. Atomic Dog Publishing, Cincinnati, OH.
38 Ritchie, J. and Lewis, J. 2003. Qualitative Research Practice: A Guide for Social Science Students and Researchers. Cromwell, UK.
39 Campbell, D. 1997. Community-controlled economic development as a strategic vision for the sustainable agriculture movement. American Journal of Alternative Agriculture 12:37–44.
40 Conservation Technology Information Center. 2008. Conservation Tillage, Nutrient Management Planning, Top Farmers' Best Management Practices. Press Release—30 January, 2008. Available at Web site http://www.conservationinformation.org/?action=about_news_topbmpjan08 (verified 11 July 2008).

Renewable Agriculture and Food Systems: 24(1); 72–84 doi:10.1017/S1742170508002457

Mapping potential foodsheds in New York State: A spatial model for evaluating the capacity to localize food production

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Accepted 15 October 2008 **Research Paper**

Abstract

Growing interest in local food has sparked debate about the merits of attempting to reduce the distance food travels. One point of contention is the capacity of local agriculture to meet the food needs of local people. In hopes of informing this debate, this research presents a method for mapping *potential* foodsheds, land areas that could *theoretically* feed urban centers. The model was applied to New York State (NYS). Geographic information systems were used to estimate the spatial distribution of food production capacity relative to the food needs of NYS population centers. Optimization tools were then applied to allocate production potential to meet food needs in the minimum distance possible. Overall, the model showed that NYS could provide 34% of its total food needs within an average distance of just 49 km. However, the model did not allocate production potential evenly. Most NYS population centers could have the majority of their food needs sourced in-state, except for the greater New York City (NYC) area. Thus, the study presents a mixed review of the potential for local food systems to reduce the distance food travels. While small- to medium-sized cities of NYS could theoretically meet their food needs within distances two orders of magnitude smaller than the current American food system, NYC must draw on more distant food-producing resources. Nonetheless, the foodshed model provides a successful template for considering the geography of food production and food consumption simultaneously. Such a tool could be valuable for examining how cities might change their food procurement to curb greenhouse gas emissions and adapt to depletion of petroleum and other energy resources necessary for long-distance transport of food.

Key words: food miles, foodshed, geographic information systems (GIS), local food, optimization

Introduction

Within the diverse literature on alternative food systems, there is a history of associating 'localness' with sustainability. This connection has been traced to the writings of Wendell Berry, Jim Hightower and Frances Moore Lappé from the 1970s, which articulated a vision for local, sustainable and just food systems[1]. Geographic proximity has been related to sustainability for a variety of reasons, encompassing the ecological, economic and social dimensions of the food system. For example, in local food systems where producers and consumers are in closer physical proximity, local food is presumed to travel shorter distances and consequently reduce the amount of energy used[2–5] and greenhouse gas emissions released[6] in the transport of foods. Similarly, local food is presumed to be marketed either directly to consumers or through shorter supply chains, enabling farmers to capture a greater share of the food dollar and thereby improve the economic viability of farms and rural communities[3,4,7,8]. Moreover, the closer relationship between farmers and the general public is purported to increase awareness of issues related to the food system[4,8]. Taken together, these reasons make a case for why local foods or food system 'localization' should be a vital component of a transition to a more sustainable food system.

The veracity of these claims has become a matter of debate in both the academic literature and the popular press. Major mainstream periodicals have recently featured articles that discuss merits of purchasing local food with regard to reducing environmental impact[9,10]. Similarly,

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articles in academic journals have questioned the assumption that local food systems are intrinsically more just or sustainable than the conventional food system[11–13]. In response to growing interest in the topic, a group of researchers from the UK reviewed the literature to test the claim that local food actually reduces emissions[14]. They concluded that a sufficient body of analysis does not exist to substantiate or refute the claims. The debate remains unresolved. However, the pressing concerns of climate change, rising energy prices and the longevity of fossil fuel supplies suggest that the degree to which societies can continue to depend on food transported long distances is a relevant question[15].

The world is increasingly urban. It is projected that in 2008 more than half of all people will live in cities[16]. In this context, if 'localizing' the food system is an important principle of or strategy for improving sustainability, a fundamental question to ask is, 'To what degree *can* food be produced locally?' Moreover, should the meaning of 'local' be context specific? While the term 'local' lacks consistent definition, various attempts have been made to estimate the capacity for circumscribed areas (individual states within the USA or, in the case of the UK, an entire country) to meet their internal food needs. Some analyses examine the potential for current production to satisfy current consumption[17–22]. Others estimate how agricultural production or diets could change to enable a larger share of food to be produced locally[18,23]. However, they all examine their respective study regions in the aggregate. In contrast, a geospatial framework may allow one to investigate the capacity to produce food locally with greater geographic precision.

To this end, the concept of a 'foodshed' offers a possible framework for such analysis. In its original meaning, 'foodsheds' define the barriers that guide the flow of food from the producer to the consumer[24], though the term has also been used to describe a food system that connects local producers and consumers[2,3,25,26]. For the purposes of this paper, a *potential local* foodshed is the land that could provide some portion of a population center's food needs within the bounds of a relatively circumscribed geographic area. This concept provides a framework for analyzing the capacity to produce food locally at the scale of an individual city. However, no standard methods exist for analyzing foodsheds. Thus, the principal goal of this research was to develop a spatial model for mapping potential, local foodsheds.

To achieve this goal, the model uses a combination of geographic information system (GIS) and optimization techniques to analyze the capacity of New York State (NYS) population centers to meet their food needs within the state. The model estimates the distance within which food could potentially be supplied and, since previous research has shown that NYS cannot supply all of its food needs[23], the share of total food needs that could be met from in-state production. Moreover, the model enables the production of foodshed maps as a tool for visualizing the geographic extent of a food supply. As home to the largest city in the nation [(New York City (NYC)], the largest protected natural area in the 48 conterminous USA states (Adirondack Park[27]), and a multi-billion dollar agriculture industry, NYS makes for an interesting test case.

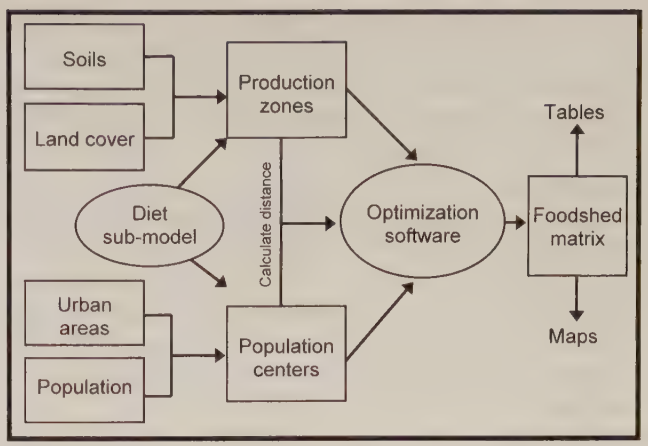

Figure 1. Simplified data flow diagram for the spatial model used to map potential local foodsheds.

Methods

We developed a hybrid spatial-optimization model to map *potential local* foodsheds and to evaluate the capacity for NYS population centers to supply their food needs within the state's boundaries. The model characterized the food production potential of the state's land and the food needs of its population centers within a GIS. The GIS provided input for an optimization model that allocated NYS food production capacity to meet the food needs of NYS population centers in the minimum possible distance. The details of each step are outlined in the subsequent sections.

Outline of model design

A broad range of data were processed to create a GIS that produced input data for the optimization model used to map foodsheds (Fig. 1). Soil and land cover data provided estimates of the relative productivity of soils and the location of agricultural land in NYS. Urban area (UA) delineations and population data were used to determine the location of population centers and the numbers of people who reside in or near them. Data from prior research on the land requirements of the human diet[23] were used to derive estimates of per capita food need and average NYS food yields.

The GIS integrated these data to produce input for the optimization model. Estimates of food production potential were calculated for each food-producing unit or production zone. Estimates of food needs were calculated for each population center. The GIS also calculated distances between all production zones and population centers. The resulting data matrices were incorporated into an optimization model that allocated available production to meet the

needs of population centers such that the distance food traveled was minimized. Output from the model was used to map and characterize potential foodsheds. All mapping and geospatial operations were performed using ArcGIS 9.1 and Manifold® System 6.5.

A new unit for representing food in the aggregate

For this analysis, a unit is needed that can be used to measure both food need and food production. To this end, this study introduces a new unit for discussing food in the aggregate: the Human Nutritional Equivalent (HNE). An HNE is a basket of food that contains representatives from all food groups combined in the proper proportions to constitute a complete diet for one person for 1 year.

The USDA Economic Research Service (ERS) set a precedent for examining the adequacy of the USA agricultural production through the lens of a complete diet in the late 1990s. Rates of diet-related chronic disease and obesity motivated ERS to examine the relationships between American dietary habits and the food system[28]. Researchers examined the adequacy of the USA food supply in light of the USDA Food Guide Pyramid (FGP) recommendations[29] and estimated the changes in USA agriculture that would be required to enable all Americans to follow these recommendations[30]. This approach offers a framework for assessing the adequacy of agricultural production in a broader context than simply measuring calories[31].

The concept of an HNE stems from this work. In theory, an HNE should represent a diet containing foods in adequate quantities and varieties to meet human nutritional requirements. Because of differences in food preferences or cultural values, diets can differ substantially in terms of specific foods included or excluded and can range from strict vegetarian to meat-centric. Thus, an HNE can reflect both dietary recommendations and food consumption preferences. As a result, the HNE is a valuable concept for comparing different strategies for meeting a population's food needs that are nutritionally comparable but may have very different land, or other resource, requirements. Such a measure could be valuable for multiple contexts, from farmland preservation to food security to the growing food versus fuel debate.

Diet and land requirements sub-model

Data from a sub-model were used to determine the composition of an HNE and the average yield of HNEs on NYS agricultural land. The sub-model was the product of previous research that calculated the area of land required to produce the annual food needs of the average person on NYS agricultural land according to a variety of diet scenarios[23]. The design of the sub-model has been described in detail in this earlier work, but its basic methodology is reviewed here in brief.

The USDA FGP was the starting point for the 42 diet treatments embedded in the sub-model. The diet treatments varied in terms of the quantity of meat and fat they contained, but all diets were balanced to provide 2300 kcal per day, an amount adequate to meet the caloric requirements of the average New Yorker. Diets were constituted of representative food commodities from each food group, but, with the exception of sugar beet, included only commodities that are produced in NYS. Per capita intake of each food commodity in each diet treatment was estimated based collectively on the quantities of meat and fat in the treatment, the food group recommendations of the FGP, the serving size of the commodity and the relative preferences for that commodity from national food consumption survey data. Total edible food need was derived by inflating estimated intake to allow for the percentage of edible food in the food system that spoils or is otherwise wasted between the farm gate and the consumer.

To determine the land requirements for each food commodity, the estimates of food need were converted into quantities of agricultural commodities (crops and livestock) by using conversion factors to account for the removal of inedible portions and transformations that occur in food processing. Next, estimates of the quantity of livestock needed were used to derive the amount of feed crops necessary to supply the food coming from livestock. Finally, the quantities of feed and food crops were divided by average NYS crop yields to determine the average land requirements of the diet.

For the sake of this research, one diet was selected, from the many available in the sub-model, to represent food need. This diet meets USDA guidelines for all food groups, and, like the typical American diet, relies on meat and eggs, rather than pulses, as the major protein source. The composition of this diet is outlined in Table 1 that reports the quantity of food from each food group that would be required to feed the average person for 1 year according to the diet assumptions inherent in the model. The quantities are expressed in terms of the farm weight of agricultural commodities required to provide the food consumed in the diet.

Since not all land resources are equally suited to tillage and annual crop production, dietary requirements are partitioned into two categories: the quantity derived from annual and high-value crops (HNE_a) and the quantity derived from perennial forages (HNE_p). The sum of these two categories equals the total quantity of food (HNE_t). The HNE_a category aggregates grains, pulses, vegetables, fruits, oils, sweeteners and grain-based livestock. The HNE_p category contains meat and milk from ruminant animals. Based on the diet shown in Table 1, an average person requires 1.25 Mg of HNE_t annually, 81% of which come from HNE_a and 19% of which comes from HNE_p. Although individual food groups are shown in Table 1, the model only differentiates between these two categories of foods, HNE_a and HNE_p.

Table 1. Constituents of a HNE[1] for the diet used in the foodshed model, expressed in farm weight of food[2] and partitioned into HNEs derived from annual and high-value crops (HNE_a), perennial forage crops (HNE_p) and all crops (HNE_t).

Food group	HNE_a	HNE_p	HNE_t
	----------Mg----------		
Grains	0.11	0.00	0.11
Vegetables	0.23	0.00	0.23
Fruits	0.19	0.00	0.19
Dairy[3]	0.07	0.19	0.26
Meat and eggs[3]	0.15	0.05	0.20
Oils	0.05	0.00	0.05
Sweeteners	0.21	0.00	0.21
Total	1.01	0.24	1.25

[1] An HNE is the amount of food needed to provide one person a complete diet that meets all nutritional requirements for 1 year. See text for more details.
[2] Farm weight of food is the quantity of agricultural commodities (i.e. wheat, fluid milk, live animals, etc.) required to produce the foods included in the diet. This weight includes nonedible portions that are removed in processing.
[3] The dietary contribution of dairy and meat is divided between HNE_a and HNE_p based on the proportion of energy in the livestock rations that comes from annual crops (HNE_a) or perennial forages (HNE_p). Published estimates of total digestible nutrients (TDN) were used to measure the available energy in the feed crops. In the case of the meat and eggs food group, perennial crops only contribute to the production of beef, the only ruminant meat included in the diets.

Estimating potential food production

The productive potential of NYS soils was determined using two sources of soils data. Spatial data on the distribution of soils were obtained from the State Soil Geographic (STATSGO) database[32]. Information on expected yields and recommended crop rotations for individual soils were obtained from the Master Soils List (MSL), a resource maintained by the Department of Crop and Soil Sciences at Cornell University and published annually by the NYS Department of Agriculture and Markets[33]. The integration of these two data sets is described below.

Data from STATSGO represent soils in a generalized manner appropriate for statewide and regional analyses[34]. Each STATSGO map unit contains multiple soil types, called components, each of which corresponds to a soil mapping unit from the county-level Soil Survey Geographic (SSURGO) database[34]. The MSL database provides information for all NYS soils, including all the mapping units in the SSURGO database. Thus, the data were integrated by matching each soil component in STATSGO to its corresponding soil in the MSL (for complete details, see Appendix 1 of Peters[35]).

Once the two databases were joined together, the expected yields and recommended rotations were calculated for each STATSGO map unit. In all cases, the value assigned to the map unit was the average for all soil components in the map unit which had agricultural potential (i.e. nonzero yields), weighted based on the percentage that each component contributed to the total map unit area (see Peters[35] for more details). Together, these data provided estimates of the spatial variability in expected yield of two indicator crops, corn (*Zea mays*) silage and hay (multiple species). Corn silage was used to indicate the productive potential for annual and high-value crops (HNE_a), and hay indicated the potential for perennial forage crops (HNE_p). In addition, these data provided estimates of the maximum number of years (out of ten) that a piece of land should be planted to corn silage, in a corn silage–hay crop rotation, without causing soil erosion that exceeds the tolerable limit defined by the USDA Natural Resource Conservation Service. These recommended rotations were used to estimate the proper proportion of annual to perennial crops in the model, in other words the proportion of land that could be devoted to producing HNE_a versus HNE_p.

The location of agricultural land in NYS was determined using the most recent land cover data available at the time the study was conducted, the 1992 National Land Cover Dataset (NLCD)[36]. The NLCD data were processed to reduce inherent error as recommended by the US Geological Survey[37]. This involved using the data at the most general level of land cover classification (agriculture, barren, forest, urban, water and wetland) and performing some spatial aggregation (see Appendix 3 of Peters[35] for details). Next, the land cover data were intersected with soils data to create spatial layers that showed the location of agricultural land cover along with expected crop yields and recommended rotations of the underlying soils.

The combined soil and land cover data displayed potential productivity at a very fine resolution; each pixel represented a 30 m by 30 m land area. A pixel could not be considered as an independent production unit for two major reasons. First, this would create a problem with more variables than could be handled in the optimization software. Secondly, such small units would not be managed independently for food production; they would be parts of larger fields. Thus, a set of data was created that represented the land area of NYS in 5 km by 5 km grid cells called production zones. For the sake of the model, each of these zones was a potential food-producing unit. The relative productive potential and land management limitations of each zone were estimated based on a spatial overlay of the production zone boundaries with the layers of combined soils and land cover data. Data from this overlay were used to derive food production potential (Eqn 1):

$$P_{ij} = (A_j \times E_{ij} \times R_{ij} \times Y_i)/\bar{E}_i \quad (1)$$

The production potential (P) of a given food category (i) for each production zone (j) was the product of the area in agricultural land cover (A), the expected yield (E) of the indicator crop, the recommended proportion of time (R) that the land can be devoted to the indicator crop and the average yield (Y) of the given food type in NYS, divided by the land area weighted average expected yield ($\bar{E}$) of the

indicator crop across NYS. The terms A, E, R and $\bar{E}$ were all calculated from the spatial data layers. The term Y was derived from the land requirements of diet sub-model and is expressed in Mg HNE per unit area.

Estimating food needs of population centers

By definition, a foodshed is the area of land from which a *population center* derives its food supply. The US Census Bureau's Urbanized Areas and Urban Clusters (UAUC) data[38] were used to identify the locations of population centers. These data delineate clusters of contiguous, highly developed land throughout the USA, and thus represent population centers as discrete geographic entities. One hundred and thirty-two of these entities exist in NYS.

For modeling purposes, it was assumed that rural NYS residents would obtain their food from a population center. Thus, a method was devised to assign each member of the rural population to a nearby urbanized area (UA) or urban cluster (UC). According to the US Census Bureau[39], the UAUC boundaries were created by aggregating smaller geographic entities, called census block groups, which exceed a threshold population density. Therefore, we estimated the number of people associated with a given population center using a GIS procedure that allocated the population of every NYS census block group[40] to the nearest UA or UC. The food consumption capacity (C) of each population center (k) for a given food category (i) was equal to the number of people (N) residing in or near the population center multiplied by the weight (W) of food needed by the average person as indicated by the diet and land-use sub-model (Eqn 2):

$$C_{ik} = N_k \times W_i \tag{2}$$

Distance between production zones and population centers

The distance between production zones and population centers was estimated based on the distance from the geographic center of each production zone to the geographic center of each population center. The distances used in the model are Euclidian (as the crow flies), not distances along transportation networks.

Optimization: allocating the available production potential

The optimization problem solved in the foodshed model is an adaptation of the classic transportation problem in which the goal is to minimize the cost of transporting goods from multiple suppliers to multiple clients. Such an approach has been used by regional planners to estimate theoretical minimum commuting distances based on the locations of housing and workplaces[41]. In this application of the foodshed model, the total population in the region of analysis was greater than the available land resources could support. Thus, the model allocated *all available land* while minimizing the distance food traveled. Were land in surplus, the model would seek to feed *all people* in the shortest total distance.

The optimization problem was set up as a matrix of producers and consumers in which each production zone is a potential supplier of food, both HNE_a and HNE_p, to each population center. The optimization software solved for the matrix of values that minimized the total food distance traveled throughout the study area. Total food distance (Eqn 3) was defined as the sum of the products of the quantity of food (F) from each category (i) allocated from each production zone (j) to each population center (k) and the distance (D) between the production zones and population centers. The value reached by the model was a *global* minimum for the entire state, but not necessarily the minimum for an individual population center since the most efficient allocation for the whole state might require that land near one population center be assigned to a more distant population center:

$$\text{Food distance} = \sum (F_{ijk} \times D_{jk}) \tag{3}$$

This optimization problem was subject to two categories of constraints. Since the study area contains more people than it can feed, the first set of constraints (Eqn 4a) required that the quantity of food (F) supplied to each population center (k) be less than or equal to the need (C) of the population center for a given type of food (i). These constraints prevent any population center from receiving more food than it needs, while allowing the model to leave the needs of some population centers unsatisfied. The second set of constraints (Eqn 4b) required that the quantity of food (F) supplied by each production zone (j) be equal to that zone's potential (P) for producing a given type of food (i). These constraints force the model to allocate all the food production potential available, and thus prevent the model from minimizing distance by allocating no food. The production potential of each production zone and the food needs of each population center were obtained using the equations described in earlier sections (Eqns 1 and 2, respectively).

$$\sum F_{ik} \leqslant C_{ik} \tag{4a}$$

$$\sum F_{ij} = P_{ij} \tag{4b}$$

Optimization was performed using the Premium Solver Platform™ v6.5 and the Extended Large-Scale LP Solver Engine v6.5 from Frontline Systems[42,43]. These programs are upgrades of the basic solver in Microsoft Excel® and are accessed through the solver dialogue box in Excel®[44,45]. Note that because this software operates within an Excel® worksheet, the organization of optimization problems is limited by the maximum numbers of rows (65,536) and columns (256) allowed by Excel®. Two columns were needed to represent each population center–food type combination (one to represent HNE_a and another for HNE_p), and several columns were used for problem setup. As a result, only 125 of the 132 NYS population

Table 2. Agricultural land area, average yields and total food production potential in NYS for each category of HNE[1].

Food category	Land[2] (10^6 ha)	Yield[3] (Mg/ha)	Production potential[4] (Tg)
HNE_a	1.16	5.32	6.14
HNE_p	1.99	1.00	1.98
HNE_t	3.15	2.58	8.13

[1] An HNE is the amount of food needed to provide one person a complete diet that meets all nutritional requirements for 1 year. The diet is partitioned into food derived from annual and high-value crops (HNE_a) and food derived from perennial forages (HNE_p). Values are also shown for the total diet (HNE_t). See text for more details.
[2] Area of land available based on 1992 land cover data for NYS and recommended crop rotations for NYS soils. Despite the age of the land cover data, the total extent of agricultural land cover does not appear to have changed much since 1992. The 2003 National Resources Inventory reports that NYS has 3.24 million ha of cropland, pasture land and cropland reserve[46]. However, because of differences in methodology and definition, the total area of agricultural land cover in NYS is substantially larger than the areas of cropland and permanent pasture reported in either the NYS annual agricultural bulletins or the 5-year Census of Agriculture. For example, recent editions of the NYS annual bulletin on agricultural statistics and the Census of Agriculture reported, respectively, that the total area in cropland and permanent pasture on farms in NYS was 2.21million ha and 2.18 million ha (authors' calculations from New York Agricultural Statistics Service[47] and USDA National Agricultural Statistics Service[48] data).
[3] Average yield for all production zones in the foodshed model.
[4] May not exactly equal the product of land and yield due to rounding error.

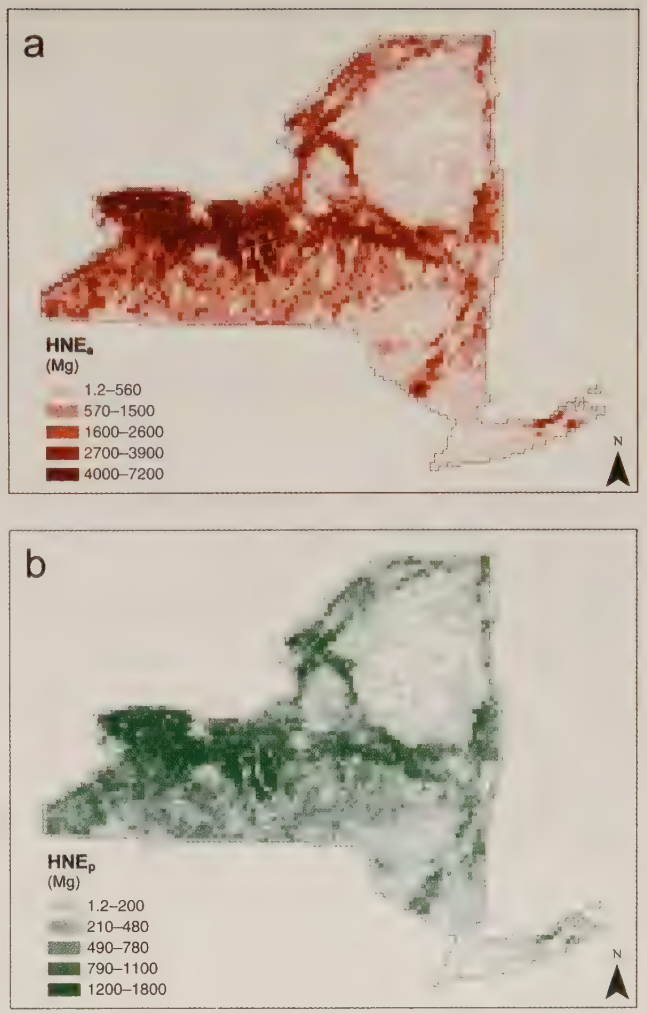

Figure 2. Maps of food production potential in NYS measured in mass of HNE. (a) Foods derived from annual and horticultural crops (HNE_a). (b) Foods derived from perennial forages (HNE_p).

centers could be accommodated by the model. Since the seven smallest NYS population centers contained only 36,737 people (just 0.2% of the total state population), they were simply excluded from the analysis. For a detailed description of the setup of the optimization problem, see the Appendix.

Results

Geography of food production potential

NYS has 3.15 million ha of agricultural land cover (Table 2). Because much of this resource has soils that are prone to erosion, nearly two-thirds of the land must be devoted to perennial forage crops, leaving slightly more than one-third for annual and high-value crop production. Yields of food, on a weight basis, are five times greater on land used for HNE_a than HNE_p. As a result, the foodshed model estimates that NYS agricultural land could produce 6.14 Tg of HNE_a and 1.98 Tg of HNE_p, given the dietary assumptions inherent in the model.

This production potential exists throughout NYS, but it is not evenly distributed (Fig. 2). As the maps indicate, the areas with relatively greater potential to produce HNE_a and HNE_p (shown in darker shades) are concentrated in the western part of the State, where soils are generally well-suited to modern agriculture and large areas are used for agricultural purposes. In contrast, the eastern portion has large areas with low or no production potential (lighter shades and unshaded areas). These low-potential areas are generally either rural areas with poor soils and mostly forested cover (most notably, the Catskill and Adirondack mountains) or predominantly UAs that contain little agricultural land.

Geography of food need

The residents of NYS are dispersed throughout a mixture of rural and urban places, but they are not evenly distributed. Of the 125 population centers considered in the model, 63% of the state's almost 19 million people reside in or near just one population center, the greater NYC area (Table 3). An additional 23% of the population resides in or near the 15 urbanized areas outside NYC, and the remaining 14% live in and around the state's more than 100 UCs. However, while NYC contains the large majority of the total and

Table 3. Urban, rural and total populations of each category of NYS population center.

Population center(s)	*N*	Population[1]		
		Urban	Rural	Total
		----------10^6 persons----------		
NYC[2]	1	11.87	0.06	11.93
Urbanized areas[3]	15	3.63	0.75	4.39
UCs[4]	109	1.08	1.54	2.62
Total	125	16.58	2.36	18.94

[1] For modeling purposes, the total population within the foodshed of a population center includes nearby rural residents (see Methods section for details). Urban populations reside within the UAs or UCs that constitute the core of a population center, and rural populations reside outside these entities. Estimates of the urban population for individual UAs and UCs were obtained from the US Census Bureau[49]. Estimates of the rural population are the difference between the total population allocated to the population center and the estimate of urban population from the US Census Bureau.
[2] The name 'New York City' is familiar to a wide audience and thus is used here to refer to the NYS portion of what the US Census Bureau defines as the 'New York-Newark' urbanized area. The population values shown include only the NYS residents.
[3] Excludes NYC.
[4] Excludes the seven smallest UCs in NYS. These population centers were omitted from the analysis for reasons discussed in the Methods section.

urban populations, most of the state's rural population live nearest to a UC or smaller urbanized area.

The individual population centers included in the model range in size from a few thousand people to more than 10 million (Fig. 3). While these population centers are distributed throughout the state, the population is heavily concentrated in the southeast corner, where NYC is located. Since per capita food need was assumed to be identical for all population centers, total food needs were distributed identically to population.

Allocating production potential to meet need: mapping foodsheds

Overall, the model shows that the capacity of NYS to produce food is insufficient to meet the total food needs. The population centers in the model required 23.6 Tg of HNE_t, whereas the production potential of NYS agricultural land could only provide 8.1 Tg of HNE_t or about 34% of the total food needs (Table 4). This capacity to meet food needs varied by food type. The NYS land base was better able to meet the needs of foods derived from perennial forages than those derived from annual and high-value crops, providing 44% of HNE_p but just 32% of HNE_a.

The allocation of available production potential by the foodshed model left food unevenly distributed among the different population centers (Table 4). The largest population center, NYC, was largely unfed. It received just

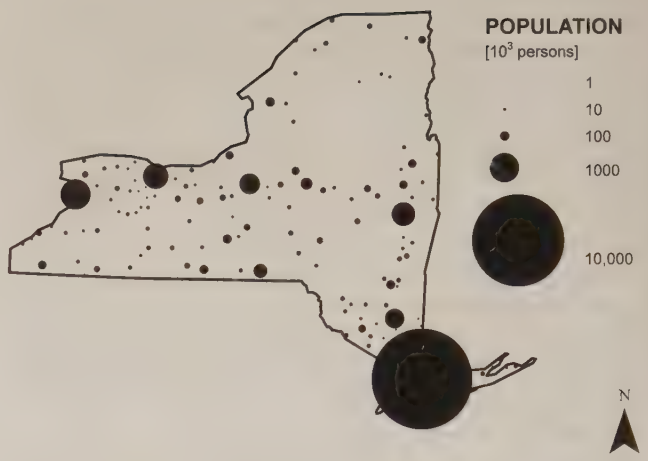

Figure 3. Locations and relative sizes of the population centers in NYS.

0.3 Tg of HNE_t, 2% of its total food needs, because the available potential was allocated to other population centers. As a result, the populations in and around most other urbanized areas and UCs had nearly all their food needs satisfied, receiving 84 and 98% of their total food needs (HNE_t), respectively.

The minimum total food distance that could be achieved by allocating food production potential to the food needs of instate population centers was 402 Tg-km (Table 5). Of this total, shipment of HNE_a was responsible for 215 Tg-km, slightly more than half of the total food distance. Shipment of HNE_p was responsible for 187 Tg-km, slightly less than half. Populations residing in and around urbanized areas were responsible for 233 Tg-km, 58% of the total food distance, whereas NYC and the populations in and around UCs were responsible for just 88 and 81 Tg-km, 22 and 20% of their respective food distances. On the average, food was transported 49 km, but bigger cities required food to be transported greater distances. Relative to the UCs, food shipped to urbanized areas traveled twice as far, and food shipped to NYC traveled ten times as far. In addition, perennial foods traveled nearly three times the distance of annual foods.

In addition to the numerical summaries described above, data from the optimization model can be summarized visually by mapping foodsheds. To demonstrate this concept, the output matrix was used to delineate boundaries for potential local foodsheds for selected NYS population centers (Fig. 4). The background of each map shows the food production potential of all production zones, and the areas shaded in color indicate the production zones that supply food to a common population center. Only the six largest population centers are displayed as it is difficult to distinguish between more than six colors in a map. The shaded areas indicate the extent of each foodshed (the area covered), and the potential productivity (shown in gray scale) indicates where food comes from within the local foodshed. One interesting spatial pattern that separates the two maps is that little of the productive potential of HNE_a

Table 4. Quantities of food[1] allocated to each category of NYS population center relative to food needs.

Population center(s)	Food need			Food allocated			Proportion of food needs satisfied		
	HNE_a	HNE_p	HNE_t	HNE_a	HNE_p	HNE_t	HNE_a	HNE_p	HNE_t
	Tg			Tg			%		
NYC	12.06	2.82	14.88	0.00	0.33	0.33	0.0	11.7	2.2
Urbanized areas	4.43	1.04	5.47	3.54	1.04	4.58	79.9	100.0	83.7
UCs	2.65	0.62	3.27	2.60	0.62	3.22	98.2	99.4	98.4
Total[2]	19.13	4.48	23.61	6.14	1.98	8.13	32.1	44.3	34.4

[1] Quantities of food are expressed in weight of HNEs. An HNE is the amount of food needed to provide one person a complete diet that meets all nutritional requirements for 1 year. The diet is partitioned into food derived from annual and high-value crops (HNE_a) and food derived from perennial forages (HNE_p). Values are also shown for the total diet (HNE_t). See text for more details.
[2] Totals may not add due to rounding error.

Table 5. Total food distance and average distance traveled by category of food[1] and category of NYS population center.

Population center(s)	Total food distance[2]			Average food distance[3]		
	HNE_a	HNE_p	HNE_t	HNE_a	HNE_p	HNE_t
	Tg-km			km		
NYC	0	88	88	0	266	264
Urbanized areas	159	74	233	45	71	51
UCs	56	25	81	22	41	25
Total[4]	215	187	402	35	94	49

[1] Quantities of food are expressed in weight of HNEs. An HNE is the amount of food needed to provide one person a complete diet that meets all nutritional requirements for 1 year. The diet is partitioned into food derived from annual and high-value crops (HNE_a) and food derived from perennial forages (HNE_p). Values are also shown for the total diet (HNE_t). See text for more details.
[2] Total food distance equals the weight of food supplied to a population center (or group of centers) times the distance traveled.
[3] Average distance traveled equals the total food distance divided by the weight of food supplied to a population center (or group of centers).
[4] Totals may not add due to rounding error.

was allocated to the NYC (purple) and Poughkeepsie–Newburgh (yellow) foodsheds, even though these cities have large populations. In contrast, the allocation of the available HNE_p was more evenly distributed. This pattern reflects the fact that NYS has greater production potential of HNE_p than HNE_a, relative to food need, and therefore can supply more HNE_p than HNE_a to NYC and Poughkeepsie–Newburgh.

In cases where the potential local foodshed could meet *all* of the food needs of its population center, Rochester (shown in green) for example, the foodshed map gives an indication of the footprint of land required to support a city. However, since not all population centers could be fed in this model, it is helpful to examine not only the size of the foodshed but also the proportion of food needs it supplies (Fig. 5). For the purpose of displaying all foodsheds in a single map, the boundaries shown in Figure 5 aggregate production zones that primarily supply the same population center. The colors indicate the percentage of total food needs that are supplied within the potential local foodshed. Both the map of HNE_a and the map of HNE_p indicate that most population centers north and west of NYC could meet the majority of their food needs from the land within the state's borders. Those that are largely underfed in the model, like NYC, lie in the south east portion of the state.

Discussion

Models are simplifications of reality. Thus, to understand the implications of a model, the results must be placed in their proper context. The purpose of the foodshed model was to examine the capacity of individual population centers to secure their food needs locally. To achieve this goal, the food system was represented merely as a universe of producers and consumers. The only obstacle in the system was distance. In essence, the model determined how much of a population center's food supply could be 'local' based on where people live relative to where agriculture occurs.

Within this context, the results provide unique perspective on the capacity of NYS population centers to meet their food needs locally. Outside of the NYC area, most population centers could meet all, or nearly all, of their food needs within the State. In contrast, NYC goes almost completely unfed. This allocation makes sense, given the design of the model. The NYC population center lies in

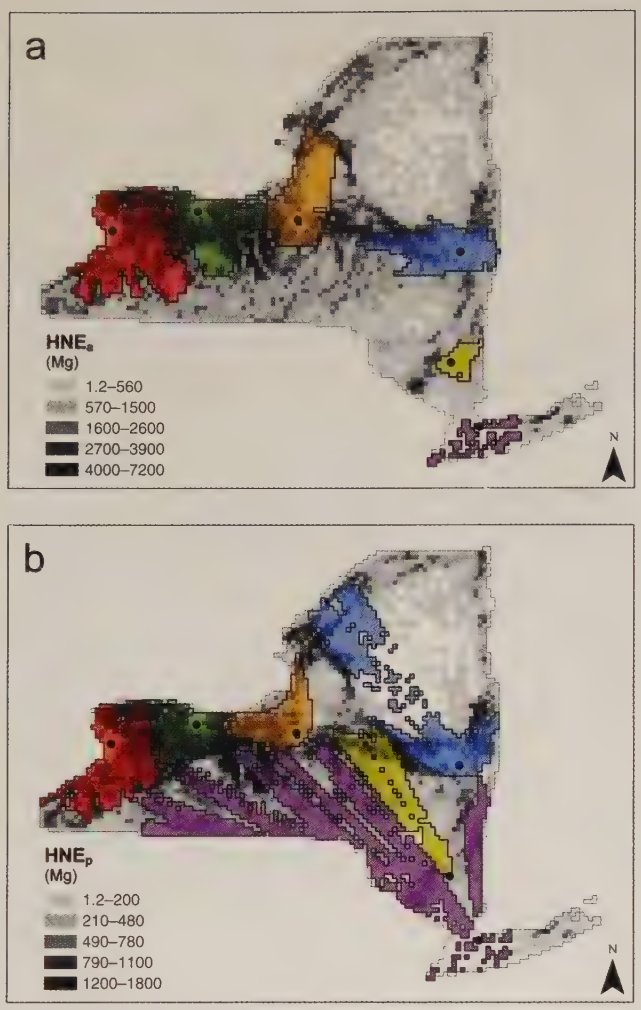

Figure 4. Maps of potential local foodsheds for the six largest population centers in NYS. Food production potential is shown in the background in grayscale. Areas shaded in color indicate the production zones allocated to a common population center (red = Buffalo, orange = Syracuse, yellow = Poughkeepsie–Newburgh, green = Rochester, blue = Albany, purple = NYC). Dots indicate the geographic center of the population center. (a) Foods derived from annual and horticultural crops (HNE_a). (b) Foods derived from perennial forages (HNE_p).

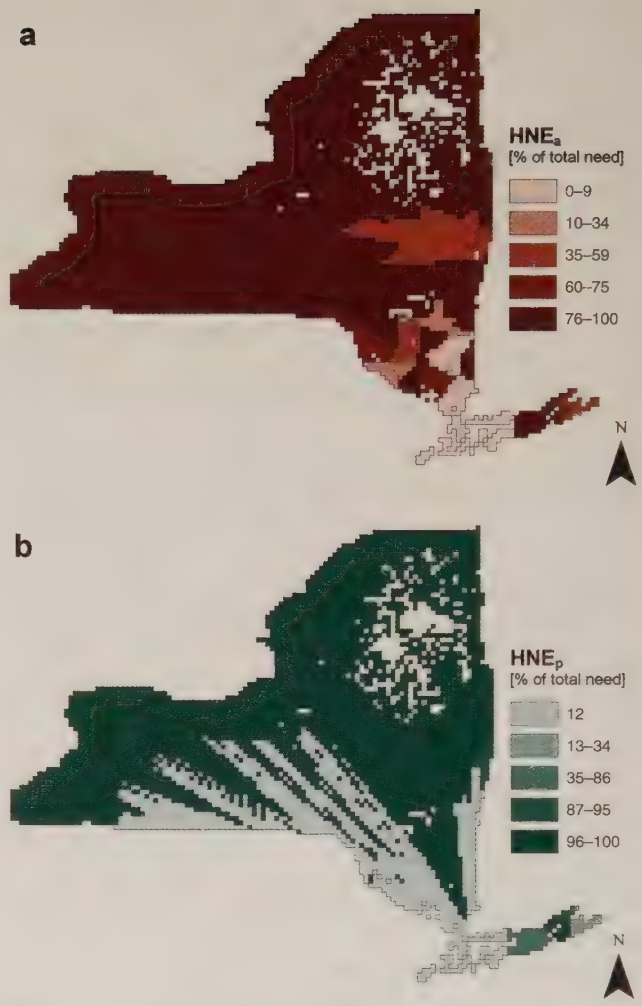

Figure 5. Maps of potential local foodsheds for 125 NYS population centers indicating the percentage of each population center's food needs that could be supplied by the potential local foodshed. (a) Foods derived from annual and horticultural crops (HNE_a). (b) Foods derived from perennial forages (HNE_p).

the southeast corner of the State, which has relatively little agriculture compared to the western half of the State. Thus, by virtue of its geography, NYC is poorly positioned to compete in a model that is designed to minimize the transport of food. Moreover, NYC has an enormous population, and even if it received all the available NYS production potential, it would meet just 55% of its total food needs. In a populous state like New York, not all food can be local.

Nonetheless, the results of the model suggest that NYS may be able to significantly reduce the distance food travels. The actual distance that food is transported through the food system is not known with certainty. However, it is frequently claimed (see, for example, Kloppenburg et al.[2], Lapping[50] and Pretty[25]) that food in the USA travels approximately 1300 miles (2080 km) from the farm to the consumer—a figure that appears to originate from a 1969 study of the US agricultural system[51]. In contrast, both the urbanized areas outside of NYC and the UCs were able to provide the vast majority of their food needs within distances two orders of magnitude shorter than the oft cited 1300 mile figure. Since these population centers account for 37% of New York's population, it appears that food system re-localization has the potential to significantly reduce the distance food travels. However, the potential reduction would probably not be two orders of magnitude. As the results show, NYC accounted for 22% of the total food distance traveled even though it received just 4% of the total food (HNE_t). Thus, were the geographic area expanded so that the food needs of NYC could be satisfied, it would have a profound influence on the average distance food travels. Given the food needs inherent in big cities relative to production potential in peri-UAs, feeding big cities may require food to travel great distances.

The application of the foodshed model in NYS imposes two limitations specific to the state's geography. First, the area of analysis lacked adequate production potential to meet the food needs of the resident population. This prevents the model from estimating the minimum distance within which *all* food needs could be supplied for *all* cities. Secondly, NYS is a relatively small geographic area, and the patterns observed in this analysis may only apply to regions with similar climate, land base, or population density. Thus, an obvious next step for foodshed research would be to apply the existing model to a larger, and more diverse, geographic area.

In addition to these geographic limitations, fundamental limitations are imposed by the way the model represents the food system. The model estimates the biophysical capacity of the land base to support food production in proportions that satisfy the nutritional needs of the resident population. However, this simplification of the food system differs from reality in three significant ways.

First, regions tend to specialize in certain types of agriculture, such as dairy, feed grains or orchard crops, whereas the model estimates production in HNEs, bundles of food in the proper proportions for a balanced diet. This prevents the model from focusing on foods that, for a variety of reasons, make sense to grow locally. For example, it may be possible for NYS to provide a greater share of its food needs, measured on a fresh-weight basis, by concentrating on foods with high water content such as fruits, vegetables and fluid milk.

Secondly, the model does not explicitly model the flow of food from its origin as an agricultural commodity at the farm gate through processing and distribution to its ultimate destination at the point of consumption. In general, this likely causes the model to underestimate the distance the food travels since the actual journey is more circuitous than simply traveling from farm to market. In addition, it requires the modeler to assume that the necessary processing infrastructure either exists or could be built within a given foodshed.

Thirdly, the model does not account for the influence of economic factors, such as economies of scale or comparative advantage, which can favor a more geographically extensive food system. These economic factors may provide a societal benefit by reducing the price of food for consumers, and the model presented here does not provide a means for analyzing such trade-offs.

One final limitation of this analysis is that the optimization goal, minimizing the distance food travels, is too simplistic to evaluate whether or not localization of the food supply is desirable for reducing greenhouse gas emissions or improving energy efficiency of the food system. Indeed, recent analysis suggests that 'food miles' are a poor indicator of environmental impact[14]. However, with additional data, the model could be adapted to optimize for either energy use or greenhouse gas emissions.

For all of the reasons listed above, the foodshed model presented here should be viewed as a first slice into the questions of how much food could and should be produced locally. Yet despite the limitations of this analysis, the foodshed model offers a flexible framework for answering questions that require one to consider the geography of food consumption and agricultural production simultaneously. As Peters et al.[31] have argued, discussion of nutritional needs and agricultural production has proceeded along separate tracks, and tools are needed that help consider the two together. The model presented here provides such a tool. Moreover, it provides a platform that can be adapted to inform much broader questions of food security and environmental impact such as, 'How might cities be fed as petroleum supplies peak and transportation becomes more expensive?' or 'How should the geography of the food system change to reduce its carbon footprint?' Indeed, foodshed modeling may offer a valuable planning tool for creating more secure and less environmentally destructive food systems if we in the sustainability community can identify which issues would most benefit from geographic analysis.

Appendix: Layout of Optimization Problem

The optimization problem was set up in a single Excel® worksheet. This worksheet integrated the three major pieces of input data (production potential for each production zone, food needs of each population center, and the distance between production zones and population centers) with the optimization goal and constraints. A description of the spreadsheet design and its relationship to the equations noted in the text is given below.

The optimization worksheet can be broken into five major elements (see Table A1 for a general schematic). First, the five by six (rows × columns) matrix of empty cells located in the upper left quadrant of the table indicates the amount of food provided from each production zone to each population center. This 'foodshed matrix' contains one row for each production zone (1–5) and two columns for each population center (A, B and C), one for HNE_a and a second for HNE_p. Each cell in this matrix was a variable in the optimization problem, meaning that the optimization software searched for the appropriate set of values for these cells that minimized food distance, within certain constraints.

Secondly, the four columns to the right of the foodshed matrix were used to constrain the model to allocate all available production potential (see Eqn 4b). The cells in the two leftmost columns calculate the total food allocated from each food category by each production zone ($\sum F_{ij}$), corresponding to the left-hand side of Equation 4b. The cells in the two rightmost columns contain estimates of the total production potential of each production zone (P_{ij}), corresponding to the right-hand side of Equation 4b and calculated as shown in Equation 1.

Table A1. Generalized layout of the optimization problem used in the foodshed model.[1]

Production zone	Food category and population center[2]						Total food supplied[3]		Food production potential[4]	
	HNE_a			HNE_p						
	A	B	C	A	B	C	HNE_a	HNE_p	HNE_a	HNE_p
1							ΣF_{a1}	ΣF_{p1}	P_{a1}	P_{p1}
2							ΣF_{a2}	ΣF_{p2}	P_{a2}	P_{p2}
3							ΣF_{a3}	ΣF_{p3}	P_{a3}	P_{p3}
4							ΣF_{a4}	ΣF_{p4}	P_{a4}	P_{p4}
5							ΣF_{a5}	ΣF_{p5}	P_{a5}	P_{p5}
Total[5]	ΣF_{aA}	ΣF_{aB}	ΣF_{aC}	ΣF_{pA}	ΣF_{pB}	ΣF_{pC}				
Food need[6]	C_{aA}	C_{aB}	C_{aC}	C_{pA}	C_{pB}	C_{pC}				

Food distance[7]: $\Sigma (F_{ijk} \times D_{jk})$

From production zone[8]	To population center					
	A	B	C	A	B	C
1	D_{1A}	D_{1B}	D_{1C}	D_{1A}	D_{1B}	D_{1C}
2	D_{2A}	D_{2B}	D_{2C}	D_{2A}	D_{2B}	D_{2C}
3	D_{3A}	D_{3B}	D_{3C}	D_{3A}	D_{3B}	D_{3C}
4	D_{4A}	D_{4B}	D_{4C}	D_{4A}	D_{4B}	D_{4C}
5	D_{5A}	D_{5B}	D_{5C}	D_{5A}	D_{5B}	D_{5C}

[1] Meaning of symbols is defined in footnotes 2 through 8. See the text for a complete description of this table.
[2] The abbreviation HNE stands for Human Nutritional Equivalents. Subscripts 'a' and 'p' indicate, respectively, foods derived from annual and high value crops and foods derived from perennial forages. See Methods section for complete definitions.
[3] Nomenclature shown indicates the sum (Σ) of the food (F) from a given food category (a or p) that has been allocated by a given production zone (1 through 5).
[4] Nomenclature shown indicates the food production potential (P) of a given production zone (1 through 5) for growing food from a given food category (a or p).
[5] Nomenclature shown indicates the sum (Σ) of the food (F) from a given food category (a or p) that has been allocated to a given population center (A through C).
[6] Nomenclature shown indicates the food needs (C) of a given population center (A through C) from a given food category (a or p).
[7] Nomenclature shown indicates the sum (Σ) of the product of the quantity of food (F) from each food category (i) allocated by each production zone (j) to each population center (k) and the distance (D) between each production zone and population center.
[8] Nomenclature indicates the distance (D) between each production zone (1 through 5) and population center (A through C).

Thirdly, the two rows directly below the foodshed matrix were used to prevent the model from exceeding the food needs of each population center (see Eqn 4a). The upper row of cells calculate the total amount of food from each category that has been allocated to each population center (ΣF_{ik}), corresponding to the left-hand side of Equation 4a. The lower row contains estimates of the total food needs from each food category for each population center (C_{ik}), corresponding to the right-hand side of Equation 4a and calculated as shown in Equation 2.

Fourthly, the five by six (rows × columns) matrix located in the lower left quadrant of the table contains estimates of the distance between each production zone and each population center (D_{jk}). This distance matrix was calculated as described in the Methods section.

Fifthly and finally, the bordered cell labeled 'food distance' calculated the total food distance traveled by multiplying the values shown in the foodshed matrix by those in the distance matrix ($\Sigma F_{ijk} \times D_{jk}$). This cell corresponds to the right-hand side of Equation 3. This cell is the value that the model seeks to minimize by iteratively changing the values in the foodshed matrix.

The schematic in Table A1 shows a generalized version of the optimization worksheet developed in Excel®. The actual optimization problem developed for the foodshed model was much larger. It included 5385 production zones, 125 population centers and two categories of food. Thus, the actual foodshed matrix contained a grand total of 1,346,250 variables. The limits placed on the total food that could be produced by each production zone or received by each population center created a total of 11,020 constraints. The size of this problem necessitated the use of the Premium Solver Platform™ v6.5 and the Extended Large-Scale LP Solver Engine v6.5 from Frontline Systems[42,43].

Acknowledgements. This research was supported in part by the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service, grant number 2005-55618-15640.

References

1 Feenstra, G.W. 1997. Local food systems and sustainable communities. American Journal of Alternative Agriculture 12(1):28–36.

2 Kloppenburg, J. Jr, Hendrickson, J., and Stevenson, G.W. 1996. Coming into the foodshed. Agriculture and Human Values 13(3):33–42.

3 Halweil, B. 2002. Home Grown: The Case for Local Food in a Global Market. Worldwatch Institute, Washington, DC.

4 Gussow, J.D. 1999. Dietary guidelines for sustainability: twelve years later. Journal of Nutrition Education 31(4):194–200.

5 Gussow, J.D. and Clancy, K.L. 1986. Dietary guidelines for sustainability. Journal of Nutrition Education 18(1):1–5.

6 Pirog, R., Van Pelt, T., Enshayan, K., and Cook, E. 2001. Food, Fuel, and Freeways: An Iowa Perspective on How Far Food Travels, Fuel Usage, and Greenhouse Gas Emissions. The Leopold Center, Iowa State University, Ames, IA.

7 Lyson, T.A. and Green, J. 1999. The agricultural marketscape: a framework for sustaining agriculture and communities in the Northeast. Journal of Sustainable Agriculture 15(2/3):133–150.

8 Magdoff, F. 2007. Ecological agriculture: principles, practices, and constraints. Renewable Agriculture and Food Systems 22(2):109–117.

9 The Economist. 2006. Voting with your trolley. The Economist. 9 December, p. 73–75.

10 Cloud, J. 2007. My search for the perfect apple. Time 169(11): 42–50.

11 Bellows, A.C. and Hamm, M.W. 2001. Local autonomy and sustainable development: testing import substitution in localizing food systems. Agriculture and Human Values 18:271–284.

12 Hinrichs, C.C. 2003. The practice and politics of food system localization. Journal of Rural Studies 19:33–45.

13 Born, B. and Purcell, M. 2006. Avoiding the local trap: scale and food systems in planning research. Journal of Planning Education and Research 26:195–207.

14 Edwards-Jones, G., Milá i Canals, L., Hounsome, N., Truniger, M., Koerber, G., Hounsome, B., Cross, P., York, E.H., Hospido, A., Plassman, K., Harris, I.M., Edwards, R.T., Day, G.A.S., Tomos, A.D., Cowell, S.J., and Jones, D.L. 2008. Testing the assertion that 'local food' is best: the challenges of an evidence-based approach. Trends in Food Science and Technology 19:265–274.

15 Peters, C.J., Bills, N.L., Wilkins, J.L., and Fick, G.W. 2009. Foodshed Analysis and Its Relevance to Sustainability. Renewable Agriculture and Food Systems 24(1):1–7.

16 United Nations Population Fund. 2007. State of World Population 2007: Unleashing the Potential of Urban Growth. United Nations Population Fund, New York, NY. Available at Web site: http://www.unfpa.org/swp/swpmain.htm (verified 16 May 2008).

17 Messing, P. 1981. The New York State Food System: Growing Closer to Home. Rodale Press, Emmaus, Pennsylvania, PA.

18 Stephens, G.R., Fleming, J.G., Gacoin, L.T., and Bravo-Ureta, B.E. 1988. Better nutrition in Connecticut: opportunities for expanding fresh produce production and consumption. Bulletin 852. Connecticut Agricultural Experiment Station, New Haven, CT.

19 Herrin, M. and Gussow, J.D. 1989. Designing a sustainable regional diet. Journal of Nutrition Education 21(6):270–275.

20 Cowell, S.J. and Parkinson, S. 2003. Localization of UK food production: an analysis using land area and energy as indicators. Agriculture, Ecosystems, and Environment 94:221–236.

21 Peters, C.J., Bills, N.L., Wilkins, J.L., and Smith, R.D. 2002. Vegetable consumption, dietary guidelines, and agricultural production in New York State—Implications for local food economies. Research Bulletin 2002–07. Department of Applied Economics and Management, Cornell University, Ithaca, NY.

22 Peters, C.J., Bills, N.L., Wilkins, J.L., and Smith, R.D. 2003. Fruit consumption, dietary guidelines, and agricultural production in New York State—Implications for local food economies. Research Bulletin 2003–02. Department of Applied Economics and Management, Cornell University, Ithaca, NY.

23 Peters, C.J., Wilkins, J.L., and Fick, G.W. 2007. Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: the New York State example. Renewable Agriculture and Food Systems 22(2):145–153.

24 Hedden, W.P. 1929. How Great Cities Are Fed. D.C. Heath and Company, New York, NY.

25 Pretty, J. 2000. Towards sustainable food and farming systems in industrialized countries. International Journal of Agricultural Resources, Governance and Ecology 1(1):77–94.

26 Feagan, R. 2007. The place of food: mapping out the 'local' in local food systems. Progress in Human Geography 31(1): 23–42.

27 New York State Adirondack Park Agency. 2003. About the Adirondack Park [Online]. Available at Web site: http://www.apa.state.ny.us/About_Park/index.html (verified 23 September 2008).

28 Kennedy, E., Blaylock, J., and Kuhn, B. 1999. On the road to better nutrition. In E. Frazao (ed.). America's Eating Habits: Changes and Consequences. USDA Economic Research Service Agriculture Information Bulletin No. 750. US Government Printing Office, Washington, DC. p. 1–4. Available at Website: http://www.ers.usda.gov/Publications/AIB750/ (verified 22 May 2007).

29 Kantor, L.S. 1999. A comparison of the US food supply with the Food Guide Pyramid recommendations. In E. Frazao (ed.). America's Eating Habits: Changes and Consequences. USDA Economic Research Service Agriculture Information Bulletin No. 750. US Government Printing Office, Washington, DC. p. 71–96. Available at Website: http://www.ers.usda.gov/Publications/AIB750/ (verified 22 May 2007).

30 Young, C.E. and Kantor, L.S. 1999. Moving toward the Food Guide Pyramid: Implications for US agriculture. In E. Frazao (ed.). America's Eating Habits: Changes and Consequences. USDA Economic Research Service Agriculture Information Bulletin No. 750. US Government Printing Office, Washington, DC. p. 403–423. Available at Website: http://www.ers.usda.gov/Publications/AIB750/ (verified 22 May 2007).

31 Peters, C.J., Fick, G.W., and Wilkins, J.L. 2003. Cultivating better nutrition: can the Food Pyramid help translate dietary recommendations into agricultural goals? Agronomy Journal 95:1424–1431.

32 USDA Natural Resources Conservation Service. 1994. State Soil Geographic (STATSGO) Database for New York State. Available at Web site: http://cugir.mannlib.cornell.edu/datatheme.jsp?id=150 (accessed April 2006).

33 New York State Department of Agriculture and Markets. 2006. Soil Group Numbers by County for 2006. Available

at Web site: http://www.agmkt.state.ny.us/AP/agservices/SOILCOUNTY.htm (accessed April 2006).
34 USDA Natural Resources Conservation Service. 1994. State Soil Geographic (STATSGO) Data Base: Data Use Information. USDA Natural Resources Conservation Service Miscellaneous Publication No. 1492. US Government Printing Office, Washington, DC.
35 Peters, C.J. 2007. Mapping potential local foodsheds in New York State: a spatial analysis of the capacity to produce food closer to the point of consumption. Ph.D. dissertation, Cornell University, Ithaca, New York.
36 US Geological Survey. 1997. 1992 National Land Cover Dataset. Available at Web site: http://landcover.usgs.gov/natllandcover.php (accessed April 2006).
37 US Geological Survey. 2000. Accuracy Assessment of 1992 National Land Cover Data. Available at Web site: http://landcover.usgs.gov/accuracy/index.php.
38 US Census Bureau. 2002. Urbanized Area and Urban Cluster Census 2000 Boundary Files. Available at Web site: http://www.census.gov/geo/www/ua/ua_bdfile.html (accessed April 2006).
39 US Census Bureau. 2002. Census 2000 Urban and Rural Classification. Available at Web site: http://www.census.gov/geo/www/ua/ua_2k.html (verified 16 June 2008).
40 US Census Bureau. 2004. Centers of Population by Block Group. Available at Web site: http://www.census.gov/geo/www/cenpop/blkgrp/bg_cenpop.html (accessed April 2006).
41 Horner, M.W. and Murray, A.T. 2003. A multi-objective approach to improving regional jobs-housing balance. Regional Studies 37(2):135–146.
42 Frontline Systems, Inc. 2005. Premium Solver Platform for use with Microsoft Excel®. Version 6.5. Frontline Systems, Inc., Incline Village, NV. Available at Web site: http://www.solver.com (verified 8 October 2008).
43 Frontline Systems, Inc. 2005. Large-Scale LP/QP Solver Engine. Version 6.5. Frontline Systems, Inc., Incline Village, NV. Available at Web site: http://www.solver.com (verified 8 October 2008).
44 Frontline Systems, Inc. 2005. Premium Solver Platform for use with Microsoft Excel®, User Guide. Frontline Systems, Inc., Incline Village, NV.
45 Frontline Systems, Inc. 2005. Premium Solver Platform: Solver Engines, User Guide. Frontline Systems, Inc., Incline Village, NV.
46 USDA Natural Resource Conservation Service. 2007. Natural Resources Inventory 2003 Annual NRI: Summary Report for all States. Available at Web site: http://www.nrcs.usda.gov/technical/land/nri03/nri03landuse-mrb.html (verified 15 February 2007).
47 New York Agricultural Statistics Service. 2006. New York Agricultural Statistics 2005–2006 Annual Bulletin. Albany, New York. Available at Web site: http://www.nass.usda.gov/Statistics_by_State/New_York/Publications/Annual_Statistical_Bulletin/2006/06-bulletin.htm (verified 23 May 2007).
48 USDA National Agricultural Statistics Service. 2004. 2002 Census of Agriculture Query Tool (v1.2). Available at Web site: http://www.nass.usda.gov/census/census02/censuscd/index.htm (verified 30 March 2007).
49 US Census Bureau. 2002. Lists of Urbanized Areas and Urban Clusters. Available at Web site: http://www.census.gov/geo/www/ua/uaucinfo.html#lists (accessed April 2006).
50 Lapping, M.B. 2004. Toward the recovery of the local in the globalizing food system: the role of alternative agricultural and food models in the US. Ethics, Place, and Environment 7(3):141–150.
51 Brown, S.L. and Pilz, U.F. 1969. US Agriculture: Potential Vulnerabilities. Stanford Research Institute, Menlo Park, CA.

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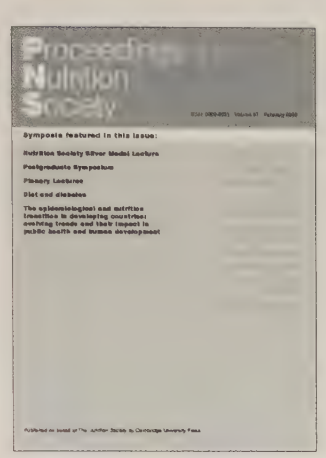
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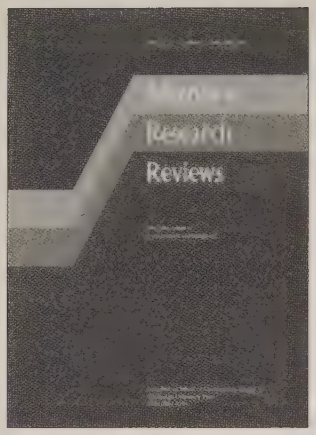

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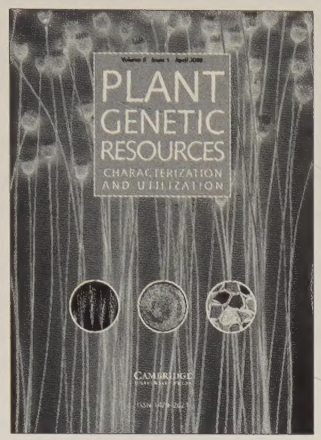

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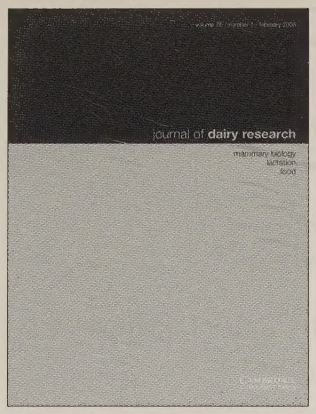

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2. Brink, R.H. Jr, Dubach, P., and Lynch, D.I., 1960. Measurement of carbohydrates in soil hydrolyzates with anthrone. Soil Science 89:157–166.
3. Greenland, D.J., and Szabolcs, I., (eds). 1994. Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK.
4. Arshad, M.A., and Coen, G.M., 1992. Characterization of soil quality: Physical and chemical criteria. American Journal of Alternative Agriculture 7:25–31.
5. Coale, F.J. 1996. Descriptions of the soil test interpretive categories used by the University of Maryland Soil Testing Laboratory. SFM-3. University of Maryland, College Park.

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